Corrosion

IN THIS ISSUE:

University Course on Corrosion Emphasizes Basic Principles 9

Refinery Corrosion Rates Below 5 mpy Achieved With Chromate Water Treatment 11

Some Corrosion Problems in Ships 18

Aluminum Propeller Resists Five-Month Salt Water Test 42

One Corroded, One Did Not— But Both Water Pumps Failed 46

Six Regional Conferences Scheduled This Fall 65

Reaction Velocity in Corrosion of Iron By Hydrogen Sulfide And the Effect of Inhibitors 84

Stress Corrosion of Steels For Aircraft and Missiles 97

Choosing Plastic Pipe For Corrosion Control 108

Insulating Properties of Cement Mortar Coating 111

Thirty Years' Experience with Silicates Inhibiting Water Systems 126

Stress Corrosion Cracking Of Austenitic Stainless Steels 131

Also: NEW PRODUCTS, a monthly summary of Timely Information. Turn to Page 56.

Complete Contents on Pages 4 and 5

CORROSION CONTROL
PROJECTS INDUSTRY
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

OFFICIAL PUBLICATION
NATIONAL ASSOCIATION
OF
CORROSION ENGINEERS

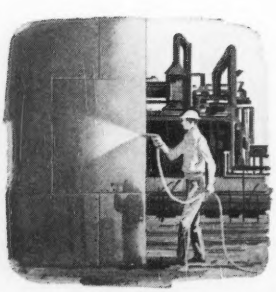
JULY
1960

Vol. 16 No. 7

AMERCOAT: COMPLETE CORROSION PROTECTION

No one coating is ideal for all applications. A coating which gives outstanding protection against strong alkalies may fail completely when exposed to acids or severe weathering.

In order to provide complete corrosion protection, the Amercoat Corporation manufactures more than 40 completely different products, each formulated to give maximum corrosion protection for specific applications. As new processes and techniques alter exposures and requirements, Amercoat's continuing research develops new products to meet those requirements. Also, advanced research and testing upgrades and improves existing products to maintain maximum protection and enduring, maintenance-free life. Amercoat protective coatings, ranging from vinyls to epoxies to phenolics, are tailor-made for long-range protection and economy in tough applications.



BONDSTRAND—A corrosion resistant, high strength, glass reinforced epoxy pipe.

Typical applications: Acid lines, waste process water, ducting for air or fumes, process lines.

DIMETCOTE—100% inorganic, zinc silicate coating

Typical applications: Tank exteriors, structural steel, cooling towers, and as a permanent primer.

AMERCOAT No. 86—A synthetic resin primer especially formulated for exceptional adhesion and compatibility with various surfaces. Can be overcoated with vinyl or epoxy coatings.

AMERCOAT No. 33—Vinyl maintenance coating unexcelled for water immersion, chemical spillage or corrosive fumes.

Typical applications: Plating tanks, tank car exteriors, structural steel, caustic tanks, tank exteriors.

AMERCOAT No. 66—A high build epoxy for tank lining or exterior maintenance coating.

Typical applications: Brine tanks, structural steel in processing areas.

AMERCOAT No. 78—An easily applied coal tar epoxy which provides exceptional resistance to water and a wide range of chemicals.

Technical data available on request. Write to:

Amercoat® CORPORATION

123

Dept. GG • 4809 Firestone Blvd. • South Gate, California

921 Pitner Ave.
Evanston, Ill.

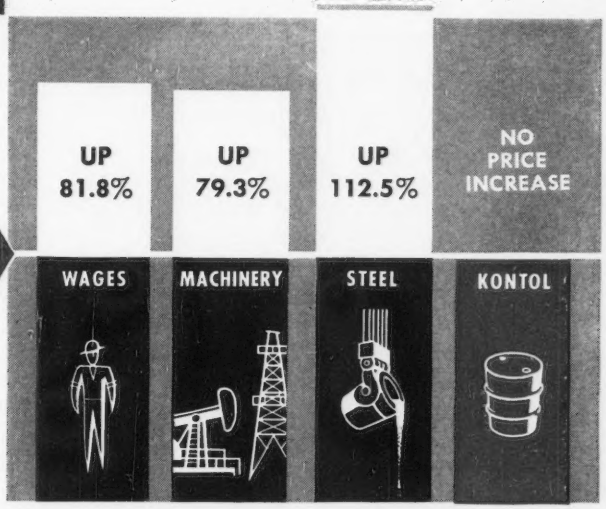
360 Carnegie Ave.
Kenilworth, N. J.

2404 Dennis St.
Jacksonville, Fla.

6530 Supply Row
Houston, Texas

111 Colgate
Buffalo, N. Y.

another TRETOLITE SERVICE report



IN A PERIOD OF RISING PRODUCTION COSTS

KONTOL *prices are still at 1948 level!*

The Tretolite research staff constantly seeks ways to produce better KONTOL* Corrosion Inhibitor formulas for less money. This concern for *cost control* as well as *corrosion control* has kept the per gallon price of KONTOL at the 1948 level! Today, when costs of equipment, material, and wages are spiraling higher, it makes more sense than ever before to invest in a sound KONTOL corrosion control program.

Ask the Man in the Red Car how it can be done.

*Registered trademark, Petrolite Corporation

KF-60-3

PETROLITE CORPORATION

TRETOLITE COMPANY
DIVISIONS
369 Marshall Avenue, Saint Louis 19, Missouri
5515 Telegraph Road, Los Angeles 22, California

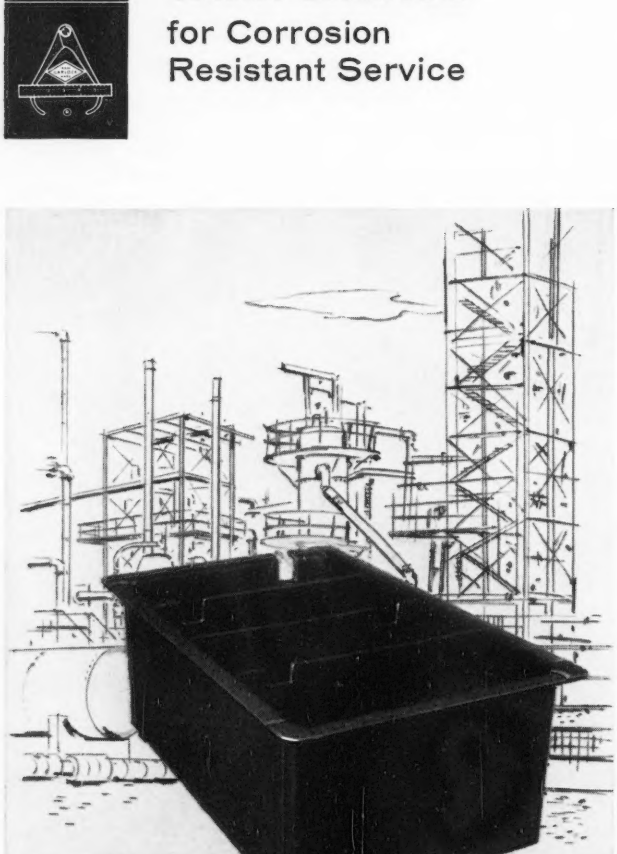
CANADA: Petrolite Corporation of Canada, Limited, Edmonton, Alberta
ENGLAND: Petrolite Limited, 20 Savile Row, London W.1
VENEZUELA: South American Petrolite Corporation, Hotel Avila, Caracas

REPRESENTATIVES

BRAZIL: WERCO, Ltda., Avenida Rio Branco 57-s/1410-11, Rio de Janeiro
COLOMBIA: W. F. Faulkner, Calle 19, No. 7-30, Office 807, Bogota
GERMANY: H. Costenoble, Guiollettstrasse 47, Frankfort, a.M.
ITALY: NYMCO S.p.A. 9, Lungotevere A. da Brescia, Rome
JAPAN: Maruwa Bussan KK, No. 3, 2-Chome, Kyobashi, Chuo-Ku, Tokyo
KUWAIT: F. N. Dahdah, Box 1713, Al Kuwait
MEXICO: R. E. Power, Sierra de Mijes, No. 125, Mexico, D. F.
NETHERLANDS: F. E. C. Jenkins, Hoefbladlaan 134, The Hague
PERU: Oilfield Import, S. A., Apartado 71, Talara
TRINIDAD: Neal and Massy, Ltd., P.O. Box 544, Port of Spain

GAR-LINE PENTON TANK LININGS

for Corrosion Resistant Service



Typical Chemical Milling Tank Penton*-Lined To Handle Hot Acids

New GAR-LINE Penton Tank Linings offer economical, high-temperature protection against corrosion. Where only more expensive materials were previously used, GAR-LINE Penton Tank Linings are proving their ability to perform as well as—and better—in many corrosive exposures involving elevated temperatures.

Unique Properties. GAR-LINE Penton Tank Linings possess characteristics that provide a highly practical means of upgrading low-cost metal substrates. Penton is applied using conventional techniques and equipment. *Mechanically*, the linings exhibit excellent tensile strength at high temperatures, good dimensional stability and low water absorption . . . *Chemically*, they resist all inorganic acids except fuming nitric and fuming sulfuric.

Widely used in chemical processing. Tanks for plating solutions, chemical milling operations, and the storage and handling of other corrosive fluids are typical of the many uses of GAR-LINE Penton Tank Linings.

Applied by carefully selected and authorized applicators. The experience of these tank lining experts guarantees satisfactory GAR-LINE Penton installation, prevent expensive failure due to improper application. Approved applicators include:

AUTOMOTIVE RUBBER CO., INC.
12580 Beech Road
Detroit 39, Michigan

BUCKLEY IRON WORKS
21 Christopher Street
Dorchester, Massachusetts

THE FORTUNE COMPANY
1906 North Mosley
Wichita 14, Kansas

GOODALL RUBBER CO.
2050 N. Hawthorne Avenue
Melrose Park, Illinois

HANSZEN PLASTICS CO.
835 S. Good-Latimer Expressway
Dallas, Texas

INNER-TANK LINING CORP.
4777 Eastern Avenue
Cincinnati 26, Ohio

ELECTRO CHEMICAL ENGRG. & MFG. CO.
750 Broad Street
Emmaus, Pennsylvania

MERCER RUBBER CORP.
Highway 46, Cor. Huyler
Little Ferry, New Jersey

METALWELD, INC.
Scotts Lane & Abbottsford Rd.
Philadelphia 29, Pennsylvania

RUBBER MILLERS, INC.
707 S. Caton Avenue
Baltimore, Maryland

ST. LOUIS METALLIZING CO.
625 S. Sarah Street
St. Louis 10, Missouri

GARLOCK

Investigate GAR-LINE Penton Tank Linings as the answer to your corrosion problems. For more information, contact the applicator nearest to you. Or, write for data on Penton; information also available on Teflon Anti-Stick and Teflon† Tank Linings. Special Products Dept., Garlock Inc., P.O. Box 612, Camden 1, New Jersey.

*Registered Trademark, Hercules Powder Company
†Registered Trademark, The DuPont Company

This Month in Corrosion Control . . .

DO YOU FEEL THE NEED for formal instruction to help you through the corrosion protection maze? If you do, then you will be interested in the course of study offered by McMaster University at Hamilton, Ontario. See Page 9.

THOSE INTERESTED IN FRESH WATER production from brackish or salt water will want to read the solutions to brine evaporator corrosion problems reported in an article beginning on Page 11. Reports are given on 20 metals and alloys. More news about salt water conversion on Page 52.

CHROMATE OR PHOSPHATE—Which is better for corrosion control of cooling water used on a catalytic reformer? How one refinery cut its corrosion rate to 5 mpy is explained in an article beginning on Page 18.

WHO DOES WHAT ABOUT TOPSIDE SHIP CORROSION? And how effective is it? If you want to learn what one inspector has discovered about this problem, and what coating systems have been found suitable turn to Page 22.

GLASS-LINED FLUE GAS stacks outlast those with other types of corrosion protection. For a case history report turn to Page 41.

TIGHT BELL-AND-SPIGOT type joints on vinyl water mains are provided by a method developed in Europe. See Page 42 for details.

USING A NON-CORRODING MATERIAL as a substitute for corroding ones does not always solve a problem. What happened to this unit on a domestic air conditioning heat exchanger is described on Page 46.

NEOPRENE CEMENT successfully defeats attack by enzymes on a food plant floor. See Page 48.

BUTYL KEEPS GROUND WATER from seeping through the foundation of Humble Oil & Refining Company's 44-story building now under construction in Houston. Turn to Page 52 for details.

IS IT A SPACE MAN? No, it's a metal worker working in the super-clean environment needed to produce high purity refractory metals. See an interesting item on Page 55.

SIX REGIONAL NACE MEETINGS this fall offer opportunities to men seeking to progress in their jobs. A roundup story on these meetings will be found on Page 65.

EFFECTIVE USE OF CERAMIC coatings on materials subjected to high temperatures involves an understanding of the fundamental mechanism by which one material becomes intimately related to another. How this knowledge is being put to use in many ways, including handling exotic metals in rockets is described in an article beginning on Page 81.

FURTHER DEFINITIVE WORK on the mechanisms of hydrogen sulfide reactions, this time in the presence of sodium chloride, with and without an oil phase and with and without inhibitors is revealed in 7-page article beginning on Page 84. Good illustrations and detailed data make it especially useful.

THOSE SEEKING SUBSTITUTES for Types 316 and 316-L will be interested in the NACE report on Page 91 concerning Type D-319-L Austenitic Chromium-Nickel-Molybdenum stainless steel.

NUCLEAR POWER PLANTS must have steam generator tubing of the highest standard of reliability, especially resistant to chloride stress corrosion cracking. How materials for this service are screened is told in an illustrated article beginning on Page 92. Materials considered include titanium, Type 347 stainless, Croloy 16-1, Nickel, Monel, Carpenter 7 Mo and 20 Cb; nickel-plated Type 347, Croloy 2¼ and carbon steel.

SCREENING OF HIGH-STRENGTH STEEL for use in aircraft and missiles to determine their susceptibility to stress corrosion cracking has been carried out in the laboratory. The work is described beginning on Page 97. Some interesting discoveries about the value of tempering at 1100 F and above are revealed. Eighteen materials were tested.

ARE YOU FACED WITH CHOOSING a plastic pipe for a corrosive condition in your plant? If so you will find helpful suggestions in the information presented beginning on Page 108. Considerable data on properties associated with corrosion resistance are given.

INSULATION OF STEEL PIPES underground with cement mortar is considered in some detail in an 11-page article beginning on Page 115. How the mortar resists galvanic currents and the effects of aging and other forces to which it is subjected are covered. Some mention of bituminous coatings on mortar is made. Cathodic protection criteria are explained.

SODIUM SILICATE HAS BEEN USED since the 1920's to protect water systems against corrosion and plugging. On Page 126 a report on 30 years' experience with this inhibitor is given. Principal reasons for failure were found to be improper inhibitor feeding rate, poor plumbing design, poor control of water temperature in hot water systems. More study is needed to determine some unsettled questions.

STRESS CORROSION CRACKING of the austenitic stainless steels continues to engage the attention of researchers. Another study of the effect of composition and heat treatment begins on Page 131. Data suggest that in the tests made, stress corrosion cracking is both electrochemical and mechanical in nature.

CONTENTS

Page

This Month in Corrosion Control 3
Why Be a Gadget Sucker?—An Editorial 7

TECHNICAL TOPICS

Page

University Course on Corrosion Emphasizes Basic Principles
By W. W. Smeltzer 9

Salt Refinery Corrosion Caused by Varying Evaporator Conditions
By John M. Turnbull 11

Refinery Corrosion Rates Below 5 mph Achieved by Chromate Water Treatment
By William A. Hess 18

Some Corrosion Problems in Ships—Part 1: Looking at Hard-to-Reach Spaces on Thin-Gauge Hulls; Part 2: Coating Systems for Thin-Scantling Construction
By Lt. Cmdr. R. S. Capp and B. J. Philibert 22

RECORD AND REPORT

Page

Glass Coatings Solve Smokestack Corrosion 41
Sea Horse Institute Studies New Problems Needing Research 41
Aluminum Propeller Resists Five-Month Salt Water Tests 42
New European Method Developed for Joining Vinyl Water Mains 42
Agglomeration Symposium to Be Held April 12-14 42
Research Contract Awarded for Graphite Missile Parts 42
High Temperature Forming Technique Used for Metals 42
Corrosion Minimized by Silver Plating in Giant Autoclave 44
Auto Exhaust Nitrogen Reduced by New System 44
Submarine Speeds May Be Increased by New Paint 44
Auto Ruling Suggested for State Air Pollution Law 44
One Corroded, One Did Not—But Both Water Pumps Failed 46
Ceramic Printed Circuits Can Be Mass Produced 46

Page

New Plants 46
Hertz Foundation Offers Engineering Scholarships 46
Neoprene Cement Controls Cracking From Enzymes 48
Kits Are Available to Build Crystal Lattice Models 48
Book News 52
Butyl Rubber to Be Water Barrier for Building Foundation 52
Salt Water Conversion May Give Power and Minerals 52
Battelle Helps Develop First Gas Cooled Reactor 52
How to Set Up a Library 52
Higher Quality Refractory Metals Milled Under Inert Atmosphere 55
Stainless Steel Alloys Solve Corrosion on Truck Brake Device 55
Sales Training Program Begun in Stainless Steel 55
1959 Engineering Index 55
New Products 56
Men in the News 59

TECHNICAL COMMITTEE ACTIVITIES

Page

Methods of Sampling Corrosion Products Discussed by T-3B 63
Five T-3G-1 Work Groups to Report at Northeast Region 63
Cathodic Protection for Stress Corrosion Discussed 63

Page

Godard Is Appointed Member of NACE Research Committee 63
Committee T-4A Elects Mercer as Vice Chairman 64
T-8B Chairman Is Elected 64

Index to Advertisers 6
Advertised in This Issue 6
Corrosion Abstracts 73

NACE NEWS

Page

Six Regional Conferences Scheduled This Fall 65
E. P. Noppel Retires After Forty Years in Corrosion Work 65
Section Calendar 65
Recent Committee Appointments 65
Canadian Region News
Edmonton Section 65
Appalachian Short Course Has Record Breaking Enrollment 67
1961 Appalachian Short Course Chairmen Named 67
National and Regional Meetings and Short Courses Calendar 67
South Central Region News
Six Symposia Listed on Advance Program for October 25-27 Tulsa Conference 68
Alamo Section 68
Houston Section 68
Greater Baton Rouge Area Section 68
Sabine-Neches Section 68
Panhandle Section 68
Central Oklahoma Section 68
East Texas Section 68
Southeast Region News
1960 Florida Short Course to Be held Nov. 7-11 in Miami 68
Birmingham Section 68
Western Region News
San Francisco Conference Has Changes Made in October 6-7 Technical Program 69
Central Arizona Section 69
San Francisco Bay Area Section 69
Portland Section 69
Los Angeles Section 69
Seagren Appointed to ISCC 69
Deaths 69
Foreign Corrosion Reports 70
North Central Region News
Twin City Section Officers 70
October 19-20 Conference to Cover Four Industries 70
Southwestern Ohio Section 70
NACE Directors Consider Metal Plaques for Awards 71
Northeast Region News
Oct. 11-14 Huntington Conference Lists Eight Symposia on Technical Program 72
Genesee Valley Section 72
Niagara Frontier Section 72
Metropolitan New York Section 72
Kanawha Valley Section 72
Technical Articles Published Since 1945 Available on Lists 72
Ohio State Short Course Registration Information 72

DIRECTORIES

NACE Officers, Directors and Staff Members 80
NACE Technical Committee Officers 142

CONTENTS

TECHNICAL SECTION

Page

Ceramic Coatings for High Temperature Service
By S. W. Bradstreet, Jr. 81

Reaction Velocity in the Corrosion of Iron by Hydrogen Sulfide And the Effect of Inhibitors
By George S. Gardner 84

Qualified Approval for D-319 Analysis Austenitic Chromium-Nickel-Molybdenum Stainless Steel—A Report of NACE Technical Unit Committee T-5A On Corrosion in Chemical Processes. Publication 60-10 91

Stress Corrosion Screening Tests of Materials For Steam Generator Tubing in Nuclear Power Plants
By D. E. White and E. G. Johnson 92
Discussion: C. M. Schillmoller, Page 96

Stress Corrosion of Steels for Aircraft and Missiles
By E. H. Phelps and A. W. Loginow 97
Discussion: Donald Warren, Franklin H. Beck, Norman D. Groves, Charles E. Fox, and M. E. Shank (with C. E. Spaeth, V. W. Cooke, And J. E. Coyne), Page 106; Replies by E. H. Phelps and A. W. Loginow, Pages 106 and 107

Considerations Involved in Choosing Plastic Pipe For Corrosion Control
By Leonard F. Sansone, Jr. 108
Discussion: Norris J. Landis, Page 110; Reply by Leonard F. Sansone, Jr., Page 110

Coal Tar Creosote Studies (Part 3—Distillation Residue Studies)
By T. R. Sweeney, T. R. Price and S. M. Miller 111

Insulating Properties of Cement Mortar Coating
By M. Unz 115

Thirty Years' Experience With Silicate as a Corrosion Inhibitor In Water Systems
By Henry L. Shuldener and Sidney Sussman 126

Effect of Composition and Heat Treatment on the Stress Corrosion Cracking of Austenitic Stainless Steels
By E. E. Denhard, Jr. 131

FOCUS ON CATHODIC PROTECTION
in the
August Technical Topics Section

Copyright 1960 by the National Association of Corrosion Engineers. Reproduction of the contents, either as a whole or in part, is forbidden unless specific permission has been obtained from the Publishers of CORROSION. Articles presented represent the opinions of their authors, and not necessarily those of the Editors of CORROSION, nor the Officers or Members of the National Association of Corrosion Engineers. Manuscripts to be considered for publication should be forwarded, together with illustrations, to the Editor of CORROSION, 1061 M & M Building, Houston 2, Texas.

Corrosion

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U.S.A., as a permanent record of progress in corrosion control. Second-class postage paid at Houston, Texas.

Vol. 16 July, 1960 No. 7

EDITORIAL STAFF

IVY M. PARKER—Editor

JAMES T. LONGINO
Technical Editor

DALE MILLER
Editorial Assistant

EDITORIAL REVIEW COMMITTEE

FRED M. REINHART, Chairman, National Bureau of Standards, Washington 25, D. C.

Mark F. Adams
A. L. Alexander
Joseph Bigos
W. W. Binger
W. B. Brooks
W. E. Bunting
I. C. Dietze
A. C. Elm
Otto H. Fenner
N. D. Greene
John J. Halbig
B. C. Haworth
T. L. Hoffman
Harry J. Keeling
Frank E. Kulman
Hugh L. Logan
Thomas A. Lowe
D. W. McDowell, Jr.
R. L. McGlasson
Dwight G. Moore
Charles C. Nathan
J. W. Nee
V. B. Pike
A. P. Richards
A. H. Roebuck
J. D. Sudbury
D. H. Thompson
Sidney Tudor
R. M. Wainwright

CORRESPONDENTS

Cecil Phillips, Jr.—Petroleum Refining
K. G. Compton—Telephone, Telegraph and Radio
S. W. Shepard—Non-Metals
Leonard C. Rowe—Transportation Industry
H. E. Stover—Fresh and Salt Water
T. F. Degnan—Chemical Industry
Gordon B. Smith—Non-Ferrous Metals
Norman D. Groves—Pulp, Paper, Mining and Food
V. M. Kalhauge—Petroleum Production and Pipe Lines
C. P. Larrabee—Ferrous Metals
Herbert W. Dieck—Power
Thomas J. Summerson—Light Metals

BUSINESS STAFF

NORMAN E. HAMNER
Managing Editor and Advertising Manager

T. J. HULL
(Executive Secretary NACE) Business Manager

BRAND and BRAND
Western States Advertising Representatives
6314 San Vicente Blvd. Los Angeles 48, Cal.

Address all communications to:
1061 M & M BUILDING
Houston 2, Texas

SUBSCRIPTION RATES (Post Paid)

NON-MEMBERS NACE, CALENDAR YEAR:
U.S. territories & possessions, Canada and Mexico ..$11
All other addresses $15

SINGLE COPIES, 1958 to DATE:
Non-members NACE .....$ 2
NACE members .....$ 1
Single copies 1956 to 1958 .....$ 2

Libraries of educational institutions, and Public Libraries, U.S., Canada and Mexico only, calendar year .....$ 4

LOST OR DAMAGED COPIES: Claims for replacement without cost must be received within 60 days of date of issue.

Foreign remittances should be by international postal or express money order or bank draft negotiable in the U. S. for an equivalent amount in U. S. funds. Entered as second class matter October 31, 1946, at the Post Office at Houston, Texas, under the act of March 3, 1879.

CORROSION Is Indexed Regularly by Engineering Index and Applied Science and Technology Index.

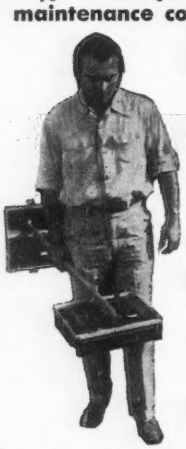
You'll need me in your chimneys

Large industrial chimneys present a real problem in protection. They must withstand high temperatures, corrosive gases and moisture condensation. For more than 25 years, Sauereisen Acid-Proof Cement No. 31 has proved itself superior in over 200 chimney installations throughout the world. Ask for Data Sheets.

Sauereisen Cements Co.
Pittsburgh 15, Pa.

SAUEREISEN
Acid-Proof CEMENT **No. 31**

90% cut in operating and maintenance cost means



CASH in the BANK for you!

New, transistorized

M-SCOPE PIPE FINDER only $189.50

Rugged, transistorized construction practically eliminates maintenance costs . . . extends battery life to a year or more. Pinpoint accuracy, greatest depth penetration make the M-scope first choice in the field!

Heavy Duty LEAK DETECTOR $295.00
Send for FREE 1960 Catalog

FISHER
Research Laboratory, Inc.
Dept. CO-3, Palo Alto, Calif.

ADVERTISED IN THIS ISSUE

A
Anodes, magnesium.....26, 40

B
Backfill, coke breeze..... 26
Bushing, dielectric..... 12
Butyl rubber.....36, 37

C
CATHODIC PROTECTION
Engineering.10, 14, 16, 26, 54
Rectifiers 69
COATINGS
Asphalt mastic 61
Chlorinated rubber..... 8
Cold Applied..... 53
Coal tar 25, 53
Coal tar-epoxy 61
Industrial 21, 23, 29, 33, 45, 57
Maintenance 35
Plastic resins 21
Corrosion Engineering..... 10

F
FIBERGLASS
Panels 71
Process vessels..... 56

H
Heat exchangers, graphite... 27

I
INHIBITORS
Oil wells..... 19
Petroleum refinery.....1, 17
Pipeline 17
INSTRUMENTS
Holiday detectors 49, 59

L
LININGS
Oil well tubing..... 13
Tank, plastic 2

M
Monel 39

P
PIPE
Chlorinated polyether ... 51
Lined, chlorinated polyether 51
Plastic, flexible 24
Polyvinylchloride, rigid... 24
PIPELINE
Felt 64
Insulation 64
Wrapping 43
Plastic tank linings..... 2
Pumps, acid resistant..... 24

R
Rectifiers, silicon..... 69

S
Sea salt, synthetic..... 38
Sandblaster, portable 58

T
Tanks, plastic lining.....2, 47
TAPE
Polyethylene 15
Polyethylene, pressure sensitive 43
Testing laboratories..... 10

V
Valves 24

W
Water treatment engineering 10
Wrought iron..... 31

INDEX TO ADVERTISERS

Vol. 16 July, 1960 No. 7

Alkydol Laboratories, Division of Reichhold Chemicals, Inc..... 29
Amercoat Corporation .....Inside Front Cover
American Hard Rubber Company Division of Amerace Corporation..... 24
Apex Smelting Company..... 40
Atlas Powder Company Chemicals Division 47
Byers, A. M. Company Wrought Iron..... 31
Carboline Company 35
Cathodic Protection Service..... 54
Chase & Sons, Inc..... 43
Clemtex, Ltd..... 58
Corrosion Engineering Directory..... 10
Corrosion Rectifying Company..... 26
Corrosion Services, Inc..... 14
Dowell .....Back Cover
Duriron Company, The.....Inside Back Cover
du Verre, Incorporated..... 56
Ekco Products Company Industrial Coatings Division..... 21
Electro Rust-Proofing Corporation..... 16
Enjay Chemical Company, A Division of Humble Oil & Refining Company.....36, 37
Fisher Research Laboratory, Inc..... 6
Garlock Packing Company, The..... 2
Good-All Electric Manufacturing Co..... 69
Hercules Powder Company Cellulose Products Department.....8, 50, 51
Humble Oil & Refining Company..... 23
International Nickel Company, Inc. Huntington Alloy Products Division..... 39
Koppers Company, Inc..... 25
Lake Products Company..... 38
May Products, Inc..... 12
National Association of Corrosion Engineers 48, 64, 70, 71, 146
National Carbon Company, Division of Union Carbide Corporation..... 27
National Glaco Chemical Corporation The Industrial Coatings Division..... 21
Pittsburgh Chemical Company Protective Coatings Division.....60, 61
Plastics and Coal Chemicals Div. Allied Chemical Corporation..... 53
Polyken Products, Dept. of The Kendall Company..... 15
Positions Wanted and Available..... 62
Resolite Corporation..... 71
Ruberoid Company, The..... 64
Sauereisen Cements..... 6
Tinker & Rasor..... 59
Tretolite Company, Division Petrolite Corporation 1
Truscon Laboratories, Division Devoe & Raynolds Co., Inc..... 33
Tube-Kote, Inc..... 49
Tubular Lining Corporation..... 13
U. S. Stoneware Company..... 45
Universal Oil Products Company..... 17
Valdura Division American-Marietta Company..... 57
Visco Products Co., Inc..... 19
Wholesale Coke Company..... 26

Why Be a Gadget Sucker?

HOPE SEEMS TO spring eternal in some people's breasts that the good genies will come up with a magical solution to their corrosion problems any day. This expectation that practical problems can be solved by recourse to the occult arts, or to some magical formula, apparently is the reason industry is afflicted with a constant stream of "gadgets," whose asserted functions are manifestly impossible under any known physical laws.

Most of these gadgets propose to control corrosion by water. This happens because it is easy to make a gadget of common, cheap materials, which will last when exposed to water at ambient or moderately hot temperatures. Also, because water is universally used and because its corrosion and scaling behavior is variable and difficult to predict without close technical study, it is a popular medium for the gadget makers to exploit.

Most of the gadgets profess to operate in one or more of the following ways:

1. A mysterious force changes the characteristics of a water stream so that the scale forming solids remain in suspension.
2. Magnetic force alters the water so that scale forming solids do not precipitate. Sometimes a claim is made that this force affects the ability of the water to corrode metals.
3. Electrical energy is applied to the water stream passing between electrodes powered either by a sacrificial anode or by an external source. Apparently direct current is favored over alternating, but this is not invariably the case.

Some of the super deluxe models may have both a sacrificial anode, a mysterious box or some other combination, the effect of which is said to prevent the water from being corrosive.

These devices have some common characteristics:

1. All of them are simple to install and require no maintenance.

2. There are no limitations on the volume of fluid that can be treated.

3. No adjustments and no supervision are required.

Generally, purveyors of these devices base their sales arguments on a stack of testimonial letters. Some of these testimonials if not all, are legitimate. Some of the men selling the gadgets apparently are not willfully misrepresenting the devices they sell, nor do they realize they don't work.

Those who buy the devices must equate testimonial with test to be convinced. Careful reading of testimonials often shows the claims of good results obtained are generalizations. No examples of failure are exposed. The assumption is that the gadgets are universally applicable and successful, no matter what the conditions.

Sales arguments are very carefully worded. This comes about because of actions that have been taken by the Federal Trade Commission against manufacturers who inadvertently made claims which could be measured against performance and were found wanting. Close reading of the sales arguments shows that claims are so general that it would be very hard indeed for the buyer to maintain later that specific measurable benefits are promised.

Sober reflection should cause any man, whether or not technically trained, to realize that the inferred benefits of these devices are wholly unrealistic (even if the theory of their operation is accepted) when weighed against the amount of energy that can be expected from the systems. In the case of some of the mysterious "boxes" whose function usually is stated in alchemic terms, there is no reason to expect any results, because no energy that can be measured is produced or even claimed to be produced.

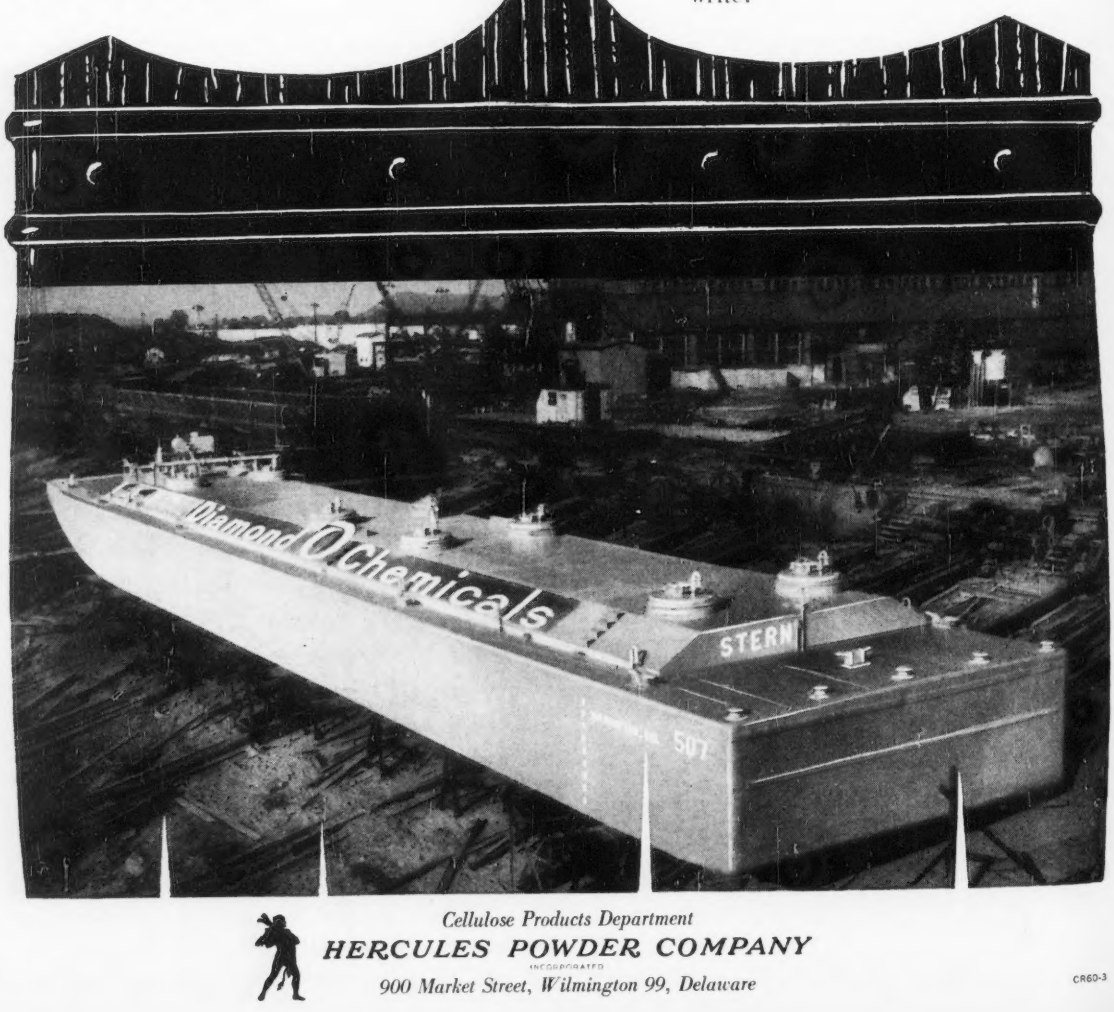
Don't be beguiled by a hypnotic spiel that promises you a solution of your corrosion problems without any effort or supervision. If it was that easy there would be no corrosion engineers and probably no corrosion.

Keep "Shipshape" with Parlon®-Based Paints

Any sailor can tell you the best way to keep his ship in condition . . . *Paint it!!*

Diamond Alkali Company also knows that paints based on Parlon chlorinated natural rubber made by Hercules are fast drying, tough, nonflammable, and resistant to alkalies, acids, chemical corrosion, and salt spray.

All paints specified in the construction of this modern chemical barge had to be Parlon-based to resist the rotting effects of salt spray and corrosive cargoes. There are Parlon-based paints to suit every unusual condition. For more information write:



Cellulose Products Department

HERCULES POWDER COMPANY

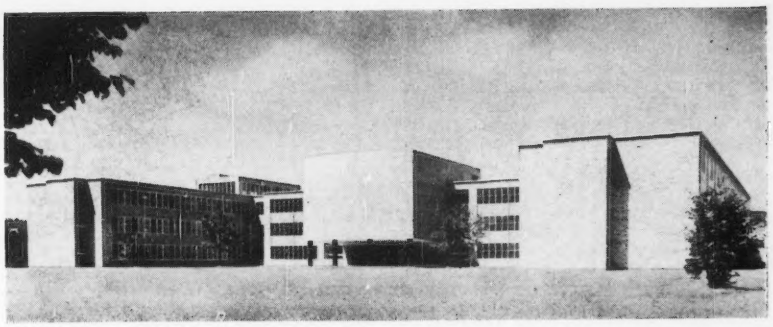
INCORPORATED

900 Market Street, Wilmington 99, Delaware

CR60-3

Abstract

Outlines curriculum of a course on corrosion principles offered at McMaster University, Hamilton, Ontario, Canada. Course demonstrates chemical and metallurgical properties of materials in corrosive atmospheres. Course is offered by Department of Metallurgy and Metallurgical Engineering to undergraduate students in their senior year. Lists curriculum outline for metal oxidation and aqueous corrosion. Five experiments are described that are used to demonstrate physicochemical and metallurgical factors of corrosion and corrosion control. 1.7.3



ENGINEERING BUILDING at McMaster University, Hamilton, Ontario, was officially opened in October, 1959. The building cost 3½ million dollars.

University Course on Corrosion Emphasizes Basic Principles*

W. W. Smeltzer
McMaster University
Hamilton, Ontario

TECHNOLOGICAL ADVANCES have increased the use of metals in more and more fields. Consequently, several university curricula include a course on corrosion principles to demonstrate the chemical and metallurgical properties of materials in corrosive atmospheres. An example is the course being offered to students of metallurgy and metallurgical and chemical engineering at McMaster University, Hamilton, Ontario, Canada. Curriculum of this corrosion course is outlined in this article.

This corrosion course is given by McMaster University's Department of Metallurgy and Metallurgical Engineering to undergraduate students in their senior year. This department, established in 1957, is composed of the science and engineering faculties. Because corrosion control combines principles of science and engineering, lectures include theory and application. Lectures are presented during the first term of the academic year: three lectures per week totaling 36 hours. Twelve laboratory periods are scheduled in conjunction with the lectures.

Emphasis is placed on principles, as seen in the curriculum outline given in Table 1. Because the students have completed two courses in physical chemistry before enrolling in the corrosion course, such advanced areas can be included as lattice defect classification of metal oxide and parabolic oxidation. Although the course emphasizes principles, consideration also is given to industrial problems in corrosion.

Texts adopted by the students for reference reading are "Introduction to Metallic Corrosion" by U. R. Evans and "Oxidation of Metals and Alloys" by O. Kubaschewski and B. E. Hopkins.

Because oxide films play a vital role in corrosion, metal oxidation is presented early in the course. The general descriptive introduction is used, then more specific areas are given: diffusion laws, lattice defect structures of oxides and thermodynamic relations to deduce the Wagner theory of parabolic scaling. Students readily grasp the two formulations of this theory based on electrical transport and diffusion parameters. An explanation of methods and results for high temperature oxidation of copper and iron illustrate the applicability of this theory. On the other hand, mechanisms for thin film formation and alloy oxidation are so complex that only qualitative principles are included. Here, industrial applications are used extensively to justify principles.

Once the students appreciate heterogenous reaction processes involving lattice defects in oxides, the complex field of corrosion begins to have similarity to the scientific principles of university curricula. The view is not adopted that corrosion is a bewildering maze of disconnected facts. The underlying principles are given and facts classified in proper groupings. Electrochemical principles of corrosion are introduced at this stage of the course.

Aqueous corrosion is presented by showing its basis in the science of electrochemistry. Then the thermodynamics of electrolytic and voltaic cells are deduced. This is substantiated with the polarization kinetics of operating cells. These principles are correlated with industrial examples to the types of corrosion outlined in Table 1.

Lectures are accompanied with a weekly 3-hour laboratory period. The students use metallographic and microscopic equipment of the Metallurgical Department. Working in groups of two, students are responsible for assembling the experimental equipment. Experiments (See Table 2) were adopted to demonstrate the physicochemical and metallurgical factors of corrosion and corrosion control.

The corrosion course at McMaster University was first presented during the 1958-59 session. Nine undergraduate and two graduate students have completed the course.

Other activities of the university in corrosion control have included a 20-

(Continued on Page 10)

TABLE 1—Corrosion Curriculum

METAL OXIDATION

A. INTRODUCTION
1. Historical survey
2. Classification of metals.
3. Structure of oxide layers:
   (a) macroscopic structure: compact, porous, compact and porous, volatile oxides.
   (b) atomic structure: metal-excess oxides with interstitial metal or anion vacancies; metal deficit oxides with metal vacancies.
4. Oxidation time laws:
   (a) five laws: parabolic, linear, cubic, logarithmic, and inverse logarithmic.
   (b) oxide models for parabolic and parabolic-linear oxidation.
   (c) parabolic-linear oxidation of molybdenum and tungsten.

B. LATTICE DEFECT CLASSIFICATION OF METAL OXIDES AND PARABOLIC OXIDATION
1. Thermodynamics and transport relations.
2. Wagner theory of parabolic oxidation.
3. Parabolic oxidation of copper and iron.
4. Transition state theory of parabolic oxidation.

C. FORMATION OF OXIDE FILMS
1. Model of leakage points in film for logarithmic oxidation.
2. Cabrera-Mott film model for inverse logarithmic oxidation.

D. OXIDATION OF ALLOYS
1. Formation of heterogeneous oxide layers:
   (a) multilayer scales
   (b) internal and selective oxidation.
2. Formation of spinal intramolecular oxides.
3. Formation of oxide solid solutions.
4. Catastrophic oxidation.

AQUEOUS CORROSION

A. INTRODUCTION
1. Historical survey.
2. Electrochemical demonstration: Faraday's Law.
3. General classification of corrosion:
   (a) uniform, intergranular and pitting corrosion.
   (b) stress corrosion cracking.

B. ELECTROCHEMICAL PRINCIPLES AND METHODS
1. Electrolytic and voltaic cells:
   (a) general arrangements: types of half cells and graphical representation.
   (b) thermodynamic aspects: free energy change and electrode potential; effect of temperature, pressure and concentration on electrode potential; standard electrode potential and convention of sign.
   (c) kinetic aspects: concentration polarization and role of diffusivity; activation polarization and Tafel equation; ohmic polarization by surface films; cathodic reactions in corrosion.
2. Measurement of electrode potentials:
   (a) reference electrodes and open circuit potentials.
   (b) the electrochemical series.
   (c) potentials of working electrodes.

C. ELECTROCHEMICAL CORROSION
1. Variable polarity of metals in contact:
   (a) galvanic contact with other metals.
   (b) differential aeration, catchment area principle.
   (c) tin plate and galvanized iron.
2. Graphical construction of corrosion processes:
   (a) potential-pH diagrams.
   (b) polarization diagrams.
   (c) cathodic protection.
   (d) inhibitors, effect on polarization.
3. Intergranular and pitting corrosion: chemical and metallurgical factors.
4. Stress corrosion cracking.

*Submitted for publication on March 24, 1960.

University Course—

(Continued From Page 9)

hour lecture series given to industrial engineers in collaboration with the Ontario section of the American Society of Metals and the Extension Department of the University of Toronto.

Acknowledgements

The author is indebted to H. P. Godard Aluminium Laboratories, Kingston, Ontario, and to R. F. Mehl, U. S. Steel Corporation, for the opportunity of engaging in corrosion studies at both industrial and university laboratories. Views given in the article resulted from discussions with former colleagues M. T. Simnad and L. Yang, General Dynamics Corporation, and with graduate students at the Department of Metallurgical Engineering, Carnegie Institute of Technology.

TABLE 2—Corrosion Laboratory

Experiment	Subject
1	Surface Oxide Layers on Metals: (a) multilayer scale on iron. (b) anodic oxide film on aluminum.
2	The Kinetics of Metal Oxidation: Parabolic Scaling of Iron.
3	Boiling Nitric Acid Test for Corrosion-Resisting Steels: ASTM designation A 262-55T.
4	Electrochemical Cells in Corrosion: (a) concentration cell. (b) aeration cell. (c) positive difference effect with zinc and zinc-platinum couples.
5	Tin Plating of Steel in Acid Bath: (a) the effect of inhibitors on deposition from solution. (b) reflow technique.

FOCUS ON CATHODIC PROTECTION

Six articles on cathodic protection will be featured in the August Technical Topics Section. Subjects to be included are telephone cables, oil field equipment, pipelines and inter-company cooperation.

One American auto manufacturer offered 73 different models of its car for sale in the USA during 1959.

•

A Corrosion Control Short Course will be held October 3-5 in conjunction with the 1960 Western Region Conference in San Francisco.

CORROSION ENGINEERING DIRECTORY

WAYNE BROYLES ENGINEERING CORP.
CATHODIC PROTECTION *Installation* DESIGN SURVEYS
P.O. Box 1169 • FAirfax 3-6858 • Houston 1, Texas

Electro Rust-Proofing Corp.
Engineering Division
ERP
Corrosion Surveys
Cathodic Protection Design
Plans • Specifications
Electrolysis Control
Testing
BELLEVILLE 9, NEW JERSEY
Atlanta • Chicago • Dallas • Monrovia

FRANCIS W. RINGER ASSOCIATES
• *Consulting Corrosion Engineers*
7 Hampden Ave. MOhawk 4-2863
NARBERTH (Suburb Phila.) PENN.

cathodic protection service
CPS
Twenty cathodic protection engineers with a combined total of over 150 years experience available to serve you with ABILITY and INTEGRITY.
Houston 4601 Stanford St.
Branch Offices: Chicago • Corpus Christi
New Orleans • Odessa • Tulsa

CATHODIC PROTECTION
• ENGINEERING
• SURVEYS • CONSTRUCTION
Systems for conventional and specialized applications
THE HARCO CORPORATION
4592 East 71st St. VUlcan 3-8787
Cleveland 25, Ohio

A. V. SMITH ENGINEERING CO.
CONSULTING ENGINEERS
Essex Bldg. Narberth, Pa.
119 Ann Street Hartford 3, Conn.

CATHODIC PROTECTION by Coreco
SURVEYS • DESIGNS INSTALLATIONS
CORROSION RECTIFYING CO., INC.
5310 ASHBROOK • MO 7-6659
HOUSTON 36, TEXAS

THE HINCHMAN CORPORATION
Consulting Engineers
"WORLD-WIDE ACTIVITIES"
Survey • Design • Supervision
Specializing In
Corrosion Control • F.C.C. Certification Tests
Electromagnetic Interference Studies
Francis Palms Bldg. Detroit, Mich.

SOUTH FLORIDA TEST SERVICE
INCORPORATED
Testing—Inspection—Research—Engineers
Consultants and specialists in corrosion, weathering and sunlight testing.
4301 N.W. 7th St. • Miami 44, Florida

CORROSION SERVICE LIMITED offers in CANADA
A Complete Service in Corrosion Engineering
Design and installation of cathodic protection systems. Supervision. Resistivity and electrolysis surveys. Selection and application of protective coatings.
17 DUNDONALD ST., TORONTO 5

ICCC Interprovincial Corrosion Control Company Limited
100 Examiner Bldg. Calgary, Alberta
CANADA
P. O. Box 187 Burlington, Ont.
CONSULTING ENGINEERS
Survey — Design — Materials and Equipment — Installations

WATER SERVICE LABORATORIES, INC.
CORROSION PREVENTION
Specialists in Water Treatment
Main Office, 615 West 131st St., N. Y. 27, N. Y.
Offices Also in Philadelphia, Washington and Richmond, Va.

CORROSION ENGINEERING
EBASCO SERVICES
INCORPORATED
TWO RECTOR STREET, NEW YORK 6, N. Y.
CHICAGO • DALLAS • PORTLAND, ORE.
SAN FRANCISCO • WASHINGTON, D. C.

"PUTTING PERMANENCE IN PIPE"
For Over 30 Years
MAYES BROTHERS, INC.
1150 McCarty Phone: OR 2-7566
HOUSTON, TEXAS

Reach more than 8000 paid readers monthly in this directory at a cost of about $1.50 per thousand. Ask for rates.

Abstract

Effect of temperature and different operating conditions in multi-effect sodium chloride evaporators on various metals is noted. A comparison between an essentially neutral brine and a highly alkaline brine indicates that large differences in corrosion can be expected between the different pH conditions. Some of the different corrosion effects that can be expected of Monel, copper alloys, stainless steels, and other metals are listed with the corrosion rates achieved in a series of tests. — 4.6.10

Salt Refinery Corrosion Caused By Varying Evaporator Conditions*

John M. Turnbull

International Salt Company
Myers, N. Y.

Introduction

HIGH RATE of corrosion experienced in the manufacture of sodium chloride by brine evaporation, especially in heat exchanger tubes, led to a series of tests to determine the most suitable materials from corrosion and economy viewpoints.

At the refining plant, evaporation of sodium chloride brine is achieved by the multiple effect system in which vapor from each preceding effect is used to heat brine in the following effect at a reduced pressure. Four effects constructed of welded Monel metal are used to evaporate the brine. Brine is circulated from the vessels through external heat exchangers by axial flow pumps; the same circulation agitates the brine in the vessels. Heat exchanger tubes originally were 90 copper-10 nickel alloy of both high and low iron content in which velocities averaged 4 to 5 feet per second.

Two grades of salt are produced at the refinery: standard evaporated salt and a highly purified salt.

Standard evaporated salt is manufactured by evaporation of an almost neutral brine (pH approximately 7.5) which contains calcium chloride, magnesium chloride and sodium chloride in solution. Suspended in the brine are crystals of calcium sulphate and sodium chloride.

A highly purified salt also is produced by evaporation of a highly alkaline brine (pH over 12) containing sodium sulphate, sodium carbonate, sodium hydroxide and sodium chloride in solution. Suspended in the brine are crystals of sodium chloride. The crystallized salt in suspension is approximately 25 percent of that suspended in the standard brine.

Production of the two grades of salt necessitates periodic emptying of the vessels and refilling with the required brine, either standard or alkaline because the two grades are not produced concurrently.

The original 90 copper-10 nickel alloy heat exchanger tubes failed in less than two years. Corrosion was erosion-corrosion type concentrated at the inlet ends, usual failures being located within 6 to 8 inches from inlet. Identical alloy heat exchanger tubes at a sister refinery had a much longer life. Since the two refineries have virtually identical mechanical operating conditions, the higher rate of corrosion at one plant might be due to the fact that a purified salt is refined by evaporation of alkaline brine only at the one plant. This variable and its corrosion rates were investigated in standard and alkaline brine.

Test Procedure

In the tests, coupons were mounted in standard way, insulated from each other and from mounting equipment. Polytetrafluorethylene was used for insulation. Previous experience with phenol-formaldehyde resin had shown a low resistance to erosion, being completely removed by abrasion in other exposures. Mounting flanges were installed in the suction sides of the circulating piping of each pan. Coupon racks were changed each time a change was made between standard and alkaline brine. Coupons were inspected at each removal.

Metals Tested

Tests were concentrated on those metals in use as materials of construction. Particular attention was paid to the cupronickels, because the high replacement of heat exchanger tubes was one of the main reasons for the corrosion testing program. Some of the metals were tried only for comparison because material costs would have been extremely high. Materials in use in various plant locations included 90 copper-10 nickel, 70 copper-30 nickel, Monel, nickel, Inconel, copper, stainless steels and Ni resist. Metals covered in these tests are listed with their nominal composition in Table 1.

First Series Of Tests

Initial series of tests were installed only in the first effect. For this series, 3-inch square specimens were used. The corner directly opposed to flow was bent at 90 degrees, ½ inch from edge to cause an obstruction to flow and to cause a stressed portion.

Two identical sets of coupons were constructed, one for each brine being evaporated (alkaline or standard), to find which of the two brines was causing the high corrosion rate.

Metals exposed in the test and a comparison of their corrosion rates are listed in Table 2. The much higher corrosion was caused by the alkaline brine. This was true of all the high copper alloys. The 316 stainless was badly stress

(Continued on Page 12)

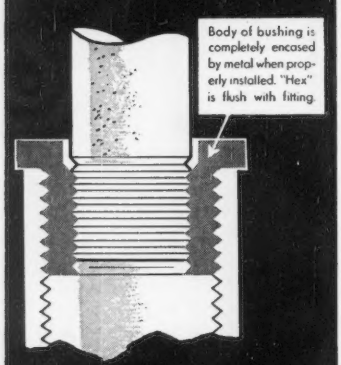
TABLE 1—Nominal Composition of Metals Tested (Weight Percent)

Metal	Ni	Cu	Cr	Si	Mo	Fe	C	Mn	Sn	Others
Monel, Cast "S"	63	30	.....	4	.....	2.0	0.1	0.75	..	.....
Monel, Cast	63	32	.....	1.6	.....	1.5	0.15	0.75	..	.....
Monel, Wrought	67	30	.....	0.1	.....	1.4	0.15	1.00	..	.....
90 Copper—10 Nickel Alloy	10	90	.....	....	.....	0.7	....	0.2	..	.....
90 Copper—10 Nickel Alloy	10	90	.....	....	.....	1.2	....	0.3	..	.....
70 Copper—30 Nickel Alloy	30	70	.....	....	.....	0.5	....	0.3	..	.....
Copper	.....	99.9	.....	....	.....	.....	....	....	..	.....
Phos. Bronze	.....	89.75	.....	....	.....	.....	....	....	10	P.25
Carp 20	29	3	20	1	2	Bal	0.07	0.75	..	Cb 8 x C
316 SS	10-14	.....	16-18	1	2-3	Bal	0.1	2	..	.....
Worthite	24	1.75	20	3.5	3.0	Bal	0.07	0.6	..	.....
Inconel	72	0.5	14-17	0.5	.....	6-10	0.15	1.0	..	.....
Ni Resist 2	18-22	0.5	2.0	1-2	.....	Bal	3	1.0	..	.....
Al Bronze	5	82	.....	....	.....	2.5	....	....	..	Al 9.5
Hast C	Bal	.....	15-18	1	16-18	4.5-7	0.15	1	..	W4.0
Nickel	99.4	0.1	.....	0.05	.....	0.15	0.05	0.25	..	.....
Incoloy	30-34	0.3	19-22	1	.....	Bal	0.1	1.5	..	.....
Everdur	.....	96	.....	3	.....	.....	....	1	..	.....
Titanium	.....	Specific Alloy Unknown						....	..	.....
Carp 7 Mo	4	.....	26-28	....	1.5	Bal	....	....	..	.....

*Revision of paper titled "Corrosion of Various Metals in Sodium Chloride Brine Under Varying Evaporator Conditions."

MAYCO

NYLON DIELECTRIC BUSHINGS



Stop Electrolysis!

■ Sandwiched between two dissimilar metals, Mayco nylon dielectric bushings prevent metal to metal contact – stop *electrolytic* action!

Able to withstand pressures in excess of 1000 lbs. and temperatures over 300°F, Mayco dielectric bushings gain added strength from clamping action of surrounding metal.

Most sizes also available with extra-heavy "Hex" to facilitate use of ordinary wrench.

Couplings and unions also available factory equipped with Mayco bushings.

Order Mayco Dielectric Bushings from your jobber or write to:

MAY PRODUCTS, INC.

BOX 427, GALESBURG, ILLINOIS

Manufacturers of: MAYCO dielectric fittings and MAYCO water softeners and filters

Salt Refinery –

(Continued From Page 11)

cracked in alkaline but much less in the standard.

Second Series Of Tests

Because the temperature range of the effects was wide (see Table 3), a second test series was used to evaluate temperature effect on the metals. From this data, depreciation rates for the different heat exchangers could be set up and possible substitution of more economical metals studied.

A new series of 8 test racks were made, two for each effect. These were changed when the process was changed from standard to alkaline brine. Some of the metals previously tested were eliminated. The 90 copper-10 nickel alloys of different iron content were tested. Because of the superiority of the high iron content in sea water, both types were included to determine if the same superiority held in brine. After exposure for 185 days in the standard brine and 125 days in the alkaline brine, samples were removed, cleaned, weighed and inspected. Table 4 gives the various corrosion rates in this series of tests.

As usual in weight loss evaluation, some figures can be misleading, because they do not take into account proportionately several serious forms of corrosion (stress corrosion cracking, intergranular attack and pitting). The figures can unduly emphasize other forms (crevice corrosion) due to the relatively small size of the coupon. Because of this, a summation of the type corrosion and the effects of same is mentioned.

TABLE 2—Corrosion Rates of Metals (in Mdd) in First Series of Tests

Metal	Alkaline	Standard
90 Copper—10 Nickel Alloy 1.2 Iron	1160	59
Inconel	28	9
SS—316	35	5
Copper	1040	92
70 Copper—30 Nickel	12	42
Monel	11	26
Al Bronze	1140	59
Hast C	.1	5
Nickel	37	37
Incoloy	24	10
Carp 20	5	4
Everdur	355	91
Carp 7 Mo	40	7
Titanium	0.8	0.8

Monel Samples

The Monel samples were characterized by crevice corrosion in the alkaline service under the insulators. Other than this, over-all corrosion was very slight. In the standard service, corrosion tended to an erosion type with some slight pitting in the hot effects (0.1 mm or less). Cast S Monel (in the annealed condition) exposed in the standard brine produced a definite etch, showing the dendritic structure of the metal. This etching was not present in the regular Monel metal cast and wrought specimens which developed pits. There was little difference in cast and wrought forms.

Copper Alloys

The 90 copper-10 nickel alloys in alkaline service had high corrosion rates. High iron and low iron alloys had extensive erosion-corrosion. Both the first effect alkaline samples had to be removed before completion of the test to prevent their destruction. No evidence of crevice corrosion occurred in these alloys in either service. The standard brine service corrosion rates were much lower than the alkaline service and appeared to be caused by erosion. Lower corrosion rates caused by the high iron content were not as marked in the standard service. The high iron content definitely lowered the corrosion rate in the alkaline brine. The alkaline service showed a strong temperature effect; the standard brine corrosion was not as dependent on temperature.

The 70 copper-30 nickel alloy corrosion was similar to Monel, with the alkaline

(Continued on Page 14)

TABLE 3—Temperatures in Evaporators

Evaporator	Standard Brine Degrees F	Alkaline Brine Degrees F
1st Effect	225	208
2nd Effect	185	169
3rd Effect	158	135
4th Effect	104	92

TABLE 4—Corrosion Rates of Metals (in Mdd) Tested in the Four Effects

Metal	ALKALINE				STANDARD			
	1st Effect	2nd Effect	3rd Effect	4th Effect	1st Effect	2nd Effect	3rd Effect	4th Effect
Monel, Cast "S"	7.0	6.5	11.2	1.4	26.8	16.9	13.6	11.3
Monel, Cast	5.1	6.5	3.3	1.0	23.8	15.8	11.5	12.4
Monel, Wrought	5.8	4.1	3.6	2.2	24.4	18.5	15.4	12.8
90 Copper—10 Nickel 0.5% Iron	695.0	137.0	110.0	40.0	72.0	46.8	52.5	44.0
90 Copper—10 Nickel 1.2% Iron	426.0	85.5	77.5	34.4	64.2	46.0	49.6	42.3
70 Copper—30 Nickel	5.9	3.4	3.6	2.8	40.5	29.7	28.9	25.4
Copper	308.0	172.0	93.5	51.5	115.8	80.4	87.5	70.3
Phos. Bronze	380.0	162.0	105.0	53.5	101.8	66.2	65.0	52.8
Carp 20	2.0	0.6	0.5	0.2	2.4	1.8	1.1	0.8
316 SS	209.0	10.9	3.9	0.6	2.9	1.5	1.0	0.6
Worthite	16.1	6.0	1.6	0.2	1.8	1.2	1.3	0.6
Inconel	31.2	20.2	12.2	4.2	6.2	3.8	6.2	2.9
Ni Resist 2	51.5	16.8	18.3	13.4	40.0	190.0	18.5	12.4

Control Discs Assure Perfect Results

TLC

TRADE MARK

the proof of quality

Just as the check of a good watermelon is the plug, the proof of the puddin' at TLC is the test disc from the actual run of the customer's pipe.

At TLC, you can be sure your tubing is lined flawlessly because during the cycling of your 172 joints on TLC's "Autotronic®" lining unit, (one oven load carries 5000 ft.), checks are made periodically on discs imbedded into a test joint. These discs are checked during the multiple lining and multiple baking cycles. Checks are made on continuity of film, character of film, thickness of film, and cure of film. One of the discs, after completion of the run, is sent to the customer for inspection, checking and approval. At TLC "Autotronic®" and "Thermo Pickling®" assure highest quality.

Ask our field engineers to show you a test plug. You'll be glad you did.

TUBULAR LINING CORPORATION

LARRY E. HEINEN, PRESIDENT

JAckson 3-7013 • P. O. Box 20015 • Houston 25, Texas

Salt Refinery –

(Continued From Page 12)

brine causing crevice corrosion and standard brine causing erosion and slight over-all pitting. This alloy was equivalent in resistance to Monel in the alkaline service and markedly more resistant than the 90 copper-10 nickel alloys.

Copper in the alkaline service had deep over-all etching and was dependent on temperature. Standard brine caused erosion type corrosion, even though samples were highly polished. Temperature did not seem as important in the standard service. Crevice corrosion was negative in both services.

Phosphor bronze had corrosion resistant characteristics similar to copper. No crevice corrosion was experienced in either service. The somewhat lower corrosion in standard brine compared to copper may be due to phosphor bronze having a higher erosion resistance.

Aluminum bronze tested in the first series of tests showed no essential differences from the other high copper alloys. All corrosion was similar to that on phosphor bronze, copper and 90 copper-10 nickel alloys.

In general, copper alloys were characterized by high erosion rates, and very high etching type corrosion in alkaline service. These alloys were relatively immune to crevice corrosion with the exception of 70 copper-30 nickel alloy, but this latter nickel alloy was relatively immune to the etching corrosion which attacked the higher copper alloys. Copper-nickel alloy would seem to be the only alloy of this group suitable for heat exchanger tubes in alkaline service and the best for standard service, although its superiority is not as marked as in alkaline service.

Stainless Alloys

Type 316 stainless steel in alkaline service was attacked by several types of corrosion. The sample in the first effect disintegrated from stress cracking. The coupon was readily broken by finger pressure and, also, was severely corroded from crevice attack under the insulator. This crevice attack continued in gradual lessening severity down to the last effect. The second effect coupon was severely pitted to a depth of about 1 mm in spots. Standard brine exposure also resulted in stress corrosion in the first effect, although not as promptly nor as completely as in alkaline service. All coupons in this service had noticeable crevice corrosion, but were untouched by erosion. Type 316 stainless steel seemed useless in brine applications in the hot effects. Its use probably would lead to catastrophic failure at some later period. Without more prolonged testing it is not safe for use in the cold effects, because stress cracking may occur at a later date.

Carpenter 20 steel was characterized by pitting attack chiefly around the circumference of the coupon and only in the first effect in alkaline service. No stress cracking was noticeable. Standard brine service produced more widely distributed pitting. Pitting was deep (1 mm), especially around the insulator edges. Corrosion of this material, especially in standard brine, was more serious than corrosion rates show because the pitting attack could be a source of much concern. Erosion of coupons was negligible.

Carpenter 7 Mo, run only in the first series of tests, had deep pitting (2 mm) next to insulators and along shear lines. This material would be useless because of the severe pitting.

Incoloy, run only in the first series of tests, had deep pitting (2 mm) and crevice corrosion. Corrosion was more pronounced in alkaline service. Pitting made that alloy unsuitable for alkaline service.

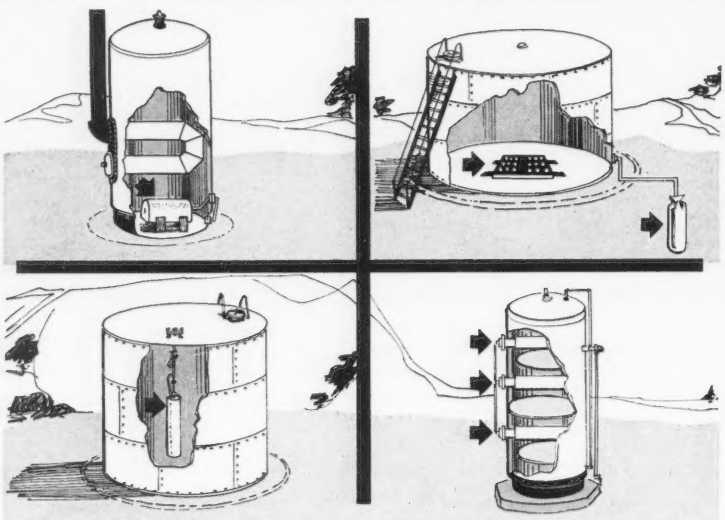
Worthite in the alkaline service had crevice corrosion and severe pitting (the deepest being 1 mm). This pitting was severe only in the first and second effects. There were indications that stress cracking had begun in the first effect coupon. In the standard brine service,

(Continued on Page 16)

Color Slide-Talk on 1960 Corrosion Show

A 35-mm color slide show of about 100 slides of exhibits at the 1960 Corrosion Show at Dallas has been prepared and is available for showing at NACE Section meetings. The show, which has a commentary on specific items exhibited, is available on a first-come, first-served basis on application to G. A. Rolak, NACE Central Office.

The show provides an opportunity for NACE members who were unable to visit the Corrosion Show personally to see some of the equipment on display. While the presentation does not include all the exhibits, it will give a good idea of the show. Presentation time should vary between an hour and an hour and a half.



HOW TO STOP CORROSION OF TANKS & HEATER TREATERS

Field experience has proved that cathodic protection offers a reliable, low-cost way to stop corrosion on steel tanks, heater treaters, filters and free-water knockouts—both externally and internally. It is effective even on vessels in contact with the most corrosive of oil field brines.

Corrosion is stopped by projecting an electrical current onto the tank surface to be protected—using either magnesium anodes or rectifiers as the current source.

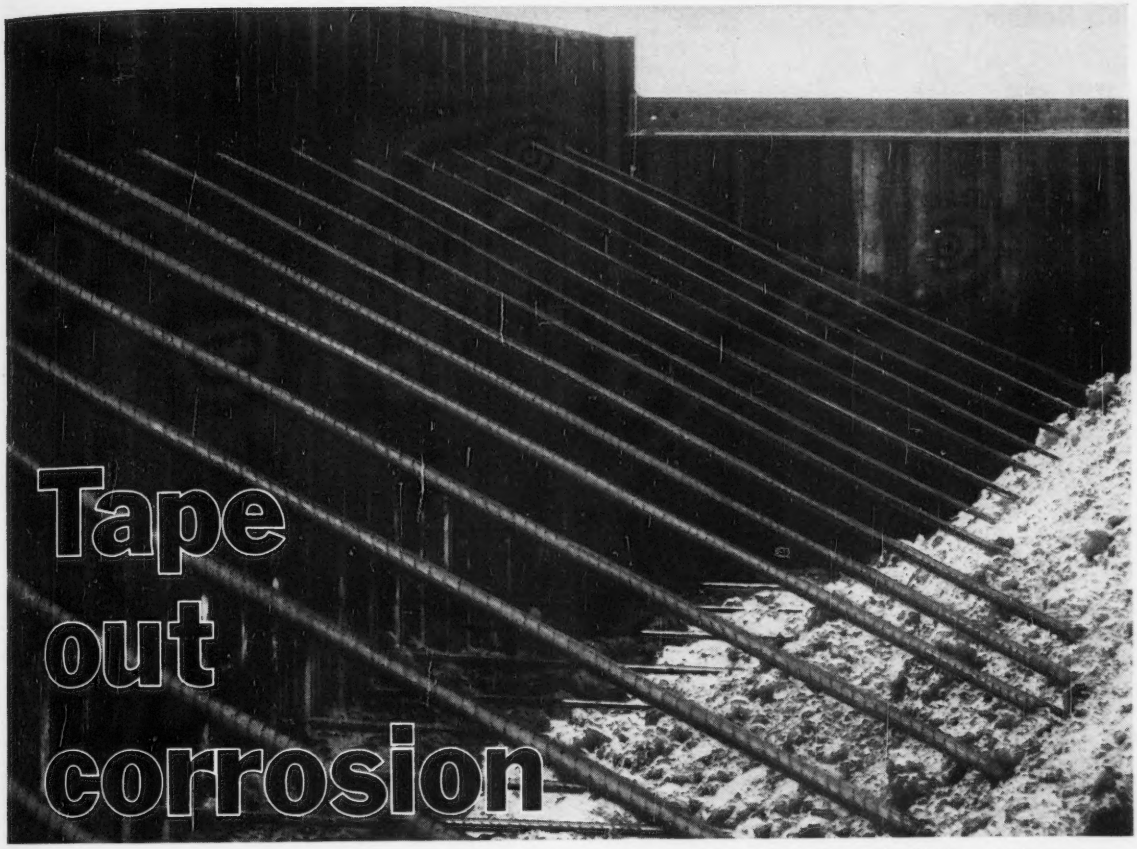
The drawing shows five of the methods by which such protection can be set up. For internal protection, anodes can be suspended from the top; inserted through side openings; or bolted to or set on wooden supports at the bottom. External protection of tank bottoms is usually achieved by burying anodes in the soil near the tank.

CSI engineers are pioneers in this work. They offer expert engineering and installation services, plus a complete line of quality supplies for both rectifier and anode installations. Prices are competitive. Call or write today.

CSI

Cleveland 13, Ohio
1309 Washington Ave.
Tel. CHerry 1-7795

CORROSION SERVICES INCORPORATED
General Office: Tulsa, Okla.
Mailing Address:
Box 787, Sand Springs, Okla.
Tel. Circle 5-1351



To assure permanent support for this seawall on Lake Michigan, a Wisconsin building contractor wrapped his anchor rods in Polyken tape. Even with an abrasive backfill of wet cinders and ashes, this builder knows Polyken will prevent corrosion and help protect buildings behind the wall.

with permanent Polyken

The durable, doubly thick adhesive of Polyken tape seals all voids—seals out corrosion

Tough, long-lasting Polyken Protective Coatings keep air and moisture from the metal. And abrasion has little effect.

Try Polyken in your plant. Get complete protection for your pipes, conduits, rods—almost anything cylindrical. Polyken is made of an inert polyethylene, with an unplasticized, non-drying film. The unusually high adhesive bonds the coating to clean surfaces without a primer.

Maintenance costs are considerably lower than with paint. Polyken goes on quickly, economically, right from the roll. No heat, no solvents or thinners, no drying or clean-up time. And keep in mind Polyken's lower water vapor transmission rate, higher electrical insulation resistance and better cold-weather handling and durability.

©1960 The Kendall Company

Find Your Nearest Distributor In The Yellow Pages

See your Polyken representative or call the Polyken tape coating distributor near you. Or simply write Polyken, 309 West Jackson Blvd., Chicago 6, Ill. (In Canada, write Polyken, Curity Ave., Toronto.)

Polyken®

EXPERIENCED IN PROTECTIVE COATINGS

THE KENDALL COMPANY
Polyken Sales Division

Salt Refinery –

(Continued From Page 14)

slight pitting (0.1 mm) occurred, with crevice corrosion negligible.

Stainless alloys were characterized by rather extensive pitting crevice corrosion and stress corrosion cracking. Of those tested, Carpenter 20 appeared to offer the most promise especially in alkaline service. These alloys pointed out the fallacy of depending on corrosion rates for a choice of material. At first inspection some of these rates indicated an ideal alloy for brine, but the sample of the ideal alloy could be riddled with stress cracks and not show any noticeable weight loss.

Miscellaneous Metals

Severe pitting occurred in Inconel in the alkaline service. The first effect sample was completely perforated in one spot. Pitting was dependent on temperature. Crevice corrosion also was severe, the area under the first effect insulator having completely disappeared. Standard brine was noticeably less severe, but pitting occurred on all samples.

Ni Resist in alkaline service had spotty accumulations of black scale with pits of 3 to 4 mm depth under the scale. The third and fourth effects had a more evenly distributed pitting. Standard service produced an over-all thinning. The second effect corrosion was greatly advanced, but no reason could be given for its accelerated corrosion. Ni Resist appeared to be an economical answer for many uses where cast iron was unsuitable.

Hastelloy C was exposed only in the first series of tests. Standard service imparted a high polish to the coupon; alkaline service gave no indication of any corrosion.

Titanium exposed only in the first test series, showed some slight crevice attack in standard service. The alkaline service appeared untouched.

Summary of Tests

These coupon tests point out that there is no economically perfect answer to the corrosion problem. Suitable metals suffer corrosion in this service, either standard or alkaline. It is necessary to balance the corrosion rate against the cost to make the best selection. In general, the copper alloys offered excellent protection from crevice corrosion, especially in the 90 percent or higher copper alloys. Stainless alloys and higher nickel content alloys had more severe crevice corrosion. In cases, where proper design cannot be used to eliminate stagnant areas (gaskets, etc.), use of these alloys should be eliminated.

Stainless alloys of the 300 series should be avoided, in brine usage where temperatures higher than 150 F are encountered. The use of 316 stainless steel in temperatures below 150 F should be watched very carefully. The type 316 coupons were not exposed long enough to determine if 316 stainless would be adequate at the lower temperatures. The use of 316 in ambient brine has been successful and offers excellent resistance to erosion attack. Stress corrosion is always a possibility, even at these low temperatures. Carpenter 20 offers good service but because of the many pits evidenced in the coupons, should be used with caution, especially in the hot effects. Worthite has been used for years in ambient brine and salt with excellent results. However, caution should be used in its exposure to hot brine in alkaline service.

Cause of accelerated attack by high alkaline brine on Inconel, Worthite and 316 stainless is not known, but there is no doubt that attack on these three alloys is greatly accelerated by the brine.

Previous tests showed Incoloy and Carpenter 7 Mo also had accelerated attack in alkaline service. No proven reason can be given for the greater corrosion rates of the high copper alloys. A possible explanation might be that the film produced in alkaline service is much less adherent or softer and is hence removed by erosion of the salt crystals more readily than the film developed in standard service.

Use of 70 copper-30 nickel alloy offers an economical answer to alkaline service comparing favorably with Monel, but in standard service Monel has a definite edge. Monel, in general, offers good protection with caution needed against crevice corrosion. It offers excellent protection against stress corrosion and fair protection against erosion. Although it has definite faults, Monel is the closest to an all around answer to corrosion problem in brine service.

In heat exchanger tubes the 70 copper-30 nickel alloy would be excellent in alkaline service and good in standard brine. On an over-all basis, considering corrosion and costs, use of 70-30 would seem to be the best alloy for tube service in most neutral or alkaline brine conditions.

•

The American plastic industry tripled its production during the 1950's from 1.6 billion pounds in 1950 to 5.4 billion pounds in 1959.

This year is your 25th anniversary. It's twenty-five years since you asked for corrosion prevention. It's twenty-five years since Electro Rust-Proofing designed and installed your first cathodic protection system.

ERP has expanded in those years. Today, ERP's worldwide organization protects pipelines, water towers, clarifiers, docks, ships' ballast tanks, and other submerged and buried metals. We've improved our methods . . . pioneered new equipment . . . brought automation to cathodic protection.

We're working now to give you even greater value, even better service for your cathodic protection dollar. To us, this milestone is not a monument. It's a stepping stone towards a corrosion-free future—with ERP.

To those who don't yet know us—we'll be happy to meet you. Just write to Dept. E 54.00.

ERP CATHODIC PROTECTION SINCE 1935

ELECTRO RUST-PROOFING CORP.
A SUBSIDIARY OF WALLACE & TIERNAN, INC.
30 MAIN STREET, BELLEVILLE 9, NEW JERSEY
CABLE: ELECTRO, NEWARK, N. J.

an ounce
of prevention
that really
PAYS
OFF...

UNICOR®

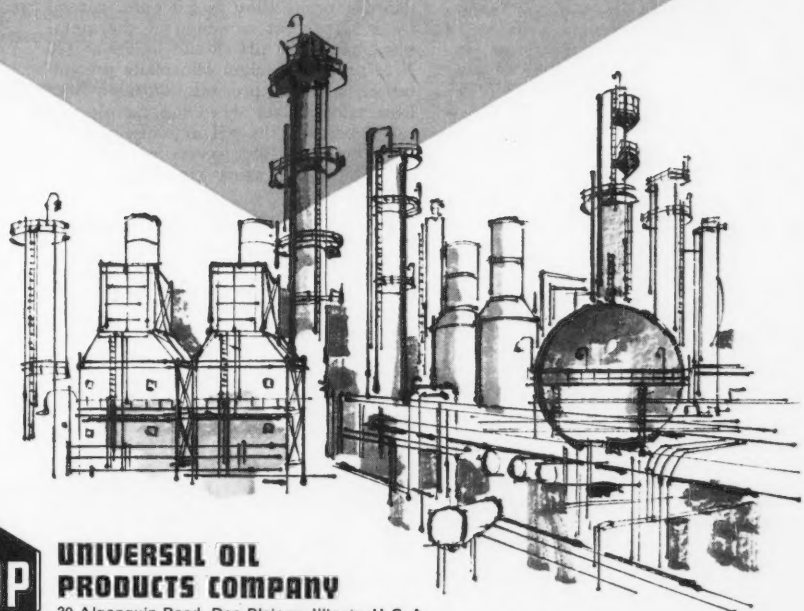
by protecting thousands of square feet of pipeline and refinery equipment

An ounce of prevention is worth a *ton* of cure . . . when it's an ounce of UNICOR.

Put 10 to 20 parts of this amazingly potent inhibitor in a million parts of crude or refined petroleum product . . . and see what happens: The UNICOR, an oil-soluble corrosion inhibitor, plates out on inner surfaces of pipeline and refinery vessels and tanks . . . provides lasting protection against corrosion.

Added at any point in your operation, UNICOR protects both metal and product, reduces downtime and cost of cleaning and maintenance, assures full flow capacity, keeps power costs at a minimum, safeguards product purity.

Write for information and samples. Address our Products Department.



See our PSE*

Correct selection and most effective use of petroleum inhibitors and additives involves expert analysis and consideration of many factors. As specialists for over a quarter-century, UOP is able to provide unparalleled field service, brought to you by a member of our staff of Product Sales Engineers*. For detailed information on the UOP family of superior inhibitors and additives call or write our Products Department.

UOP®

UNIVERSAL OIL PRODUCTS COMPANY

30 Algonquin Road, Des Plaines, Illinois, U.S.A.

WHERE RESEARCH TODAY MEANS PROGRESS TOMORROW

Refinery Corrosion Rates Below 5 mpy Achieved by Chromate Water Treatment*

William A. Hess

Standard Oil Company of Ohio
Cleveland, Ohio

Abstract

Describes water treatment tests conducted to control corrosion to a maximum of 5 mpy at a refinery's catalytic reformer. Compares corrosion rates obtained in two proprietary systems: Chromate and phosphate. Analyses of well water used and the circulating water in the two treatments are given in tabular form. 8.4.3

Introduction

EVALUATION OF water treatment was made at Standard Oil Company's Lima (Ohio) Refinery to reduce the corrosion rate to a minimum set at 5 mpy. A catalytic reformer was used for the tests because changes in water treatment method could be made easily.

Description of Water System

The reformer unit had a capacity of 60,000 gallons; the make up water came from two wells with fairly uniform analysis and a water temperature of about 55 F.

The cooling tower was a two cell induced draft type with a design range of 35 F and a 15 F approach at 75 F wet bulb. Circulation rate was 5600 gpm with two pumps and a third pump for standby or extra capacity during the summer.

Thirteen condensers and coolers and a four-section finned tube unit used recirculated cooling water. Three condensers used once-through well water for cooling to take advantage of the water's 55 F temperature. The effluent from these bundles flowed to the cooling tower as make up with a piping arrangement at the outlet for adjustment of the tower water concentration.

Typical analysis of the well water used as tower make up is given in Table 1. Hardness was about 550 ppm, 300 ppm of this being calcium hardness and the remainder magnesium hardness. High hardness leads to considerable difficulty with calcium phosphate precipitation when a phosphate type treatment is used. Hydrogen sulfide contributed to the corrosive character of the water. In its reaction with the ferrous metal, black ferrous sulfide formed which deposited out on the equipment surfaces. In another cooling tower system where well water H_2S content approached 4 ppm, considerable difficulty was experienced because of a complete reduction of the chromate in the treatment.

Initial Treatment

The reformer first went on stream in September, 1954. A proprietary low phosphate, high pH, scale prevention water treatment was used. Sulfuric acid injections into the tower for pH control were made with a hand controlled pump. During this run the waterside of the hot receiver condensers became scaled, and the water outlet temperatures ran as high as 150 F. To remove the scale, injections of inhibited hydrochloric acid were made into the cooling water at the water inlet nozzle. When the unit was down for inspection, a noticeable amount of metal loss accompanied by pitting was found on the shells of the condensers that had water on the shell side. The 70-mil loss was attributed partly to the acid cleaning.

To reduce the amount of fouling and corrosion, corrosion controlling water treatment was established. Treatment level was increased to maintain an 8 to 12 ppm metaphosphate residual in the circulating water. The pH was lowered to a range of 6.0 to 6.5, and concentration cycles were maintained at 2.0. A mercaptobenzothiozol (MBT) type inhibitor was recommended to protect the brass tubes at this low pH range. Because chlorine was used as a biocide, the MBT was slug fed when there was no chlorine residual.

Maintaining the pH within the prescribed range presented problems. Controlling the acid pump by hand caused the pH to fluctuate widely, allowing the pH to drop as low as 4.0 in some instances. To eliminate this trouble, a recorder-controller system was installed. The water consulting company recommended controlling the pH at 6.5 to 7.0 until the system became stabilized and operating personnel became acquainted with the equipment. After one month of successful operation at this range, the pH range was dropped back to 6.0 to 6.5.

Typical circulating water analysis using phosphate treatment with 1.7 concentrations is given in Table 2. Calcium hardness is 450 ppm and the orthophosphate concentration is 9.0 ppm, caused by a 50 percent reversion of the metaphosphate. The pH should be 5.9 at 120 F to prevent calcium phosphate precipitation; however, precipitation must have been taking place when the sample was taken because the pH actually was 6.9.

In January, 1956, severe corrosion of all components using circulating water was reported, especially in the six condensers with water on the shell side. Pitting was general on the cross-baffles near the tube sheets with pits to 5/32 inches in depth on the shells.

In June, 1956, the reforming unit was down for a catalyst change. When the bundles were pulled from the condensers with water on the shell side, heavy corrosion was found on the shells, the patterns showing heaviest corrosion adjacent to the baffle plates. This was due largely to areas of low velocity adjacent to the location the bundle baffles would take when in the shell. Rates of 12 and 15 mils per year were reported for corrosion coupons removed from the system at this time. During this shutdown the tower basin was drained and found to contain a large amount of mud. A large percentage of this mud was calcium phosphate and iron phosphate. This represented a considerable loss in money expended for treating chemicals. Condenser bundles using once-through well water in the tubes had a black sulfide deposit in the tubes and over all water box surfaces. Water consultants said that metaphosphate treatment would not give protection against this sulfide attack.

Up to this time, water consultants had installed a brass and a steel corrosion coupon coupled together to simu-

(Continued on Page 20)

TABLE 1—Typical Well Water Analysis*

	Well 35	Well 36
HCO_3 as $CaCO_3$	336	330
Total hardness as $CaCO_3$	546	552
Ca as $CaCO_3$	308	300
Mg as $CaCO_3$	238	252
SO_4 as $CaCO_3$	200	208
SiO_2	12.3	12.3
Fe	1.1	0.5
Cu	.....	.....
Cl	24	30
H_2S	0.4	2.0
pH	7.7	7.6

* All figures are parts-per-million except H_2S and pH.

TABLE 2—Typical Circulating Water Analyses in Phosphate and Chromate Treatments

	Phosphate	Chromate
Total Alkalinity as $CaCO_3$	72 ppm	50 ppm
Total Hardness as $CaCO_3$	830 ppm	1536 ppm
Ca Hardness as $CaCO_3$	450 ppm	848 ppm
Mg Hardness as $CaCO_3$	380 ppm	688 ppm
Fe (total)	1.8 ppm	.....
Cu	0.02 ppm	.....
Phosphate (total)	18 ppm	.....
Phosphate (Ortho)	9 ppm	.....
Phosphate (Meta)	9 ppm	.....
Phosphate (total as PO_4)	.....	6.1 ppm
Phosphate (Ortho as PO_4)	.....	1.3 ppm
Chromate as CrO_4	.....	25 ppm
Total dissolved solids	1440 ppm	1800 ppm
Conductivity (Micromhos/cm)	1600	.....
pH	6.9	6.7
Cycles of Concentration	1.7	2.46
pH where $Ca_3(PO_4)_2$ could precipitate at 120 F	5.9	6.2
Stability Index at 120 F	7.1	7.6

★ Revision of a paper titled "Four Years' Experience in Treating a Cooling Water System for Corrosion Control" presented at the 1959 North Central Region, National Association of Corrosion Engineers, Cleveland, Ohio, October 20-22, 1959.

before...

...and after

with *Visco* corrosion control!

HERE are several sets of typical before and after coupon test figures in wells now getting Visco Anti-Corrosion Treatment. Estimate the *tons* of well equipment metal saved by Visco Treatment, and you get an idea of the *dollars* saved in labor and replacement costs . . .

Well	Maximum Weight Loss—Mils/year	
	Before Visco	With Visco
1.	11.00*	0.02
2.	4.90	0.40
3.	8.10*	0.86
4.	7.50	0.08
5.	16.00*	1.30

** These wells receiving "anti-corrosion" treatment. Replaced by Visco.*

1 mil=.001 inch. A corrosion rate of 216 mils per year means that the corrosive attack, if uniform, would have corroded away the entire surface of the metal to a depth of .216 inches in a year. However, the real danger of high corrosion rates, as the coupon shows, is the much deeper and faster penetration occurring at localized areas.

These are not super-success figures. Chances are high that Visco can equal or better these results in *your* wells. Phone, Houston, JAckson 8-2495, or write for positive Visco action today.

VISCO PRODUCTS COMPANY
Incorporated
1020 Holcombe Boulevard • Houston 25, Texas

Visco® ... CONSISTENTLY EFFICIENT OIL FIELD CHEMICALS

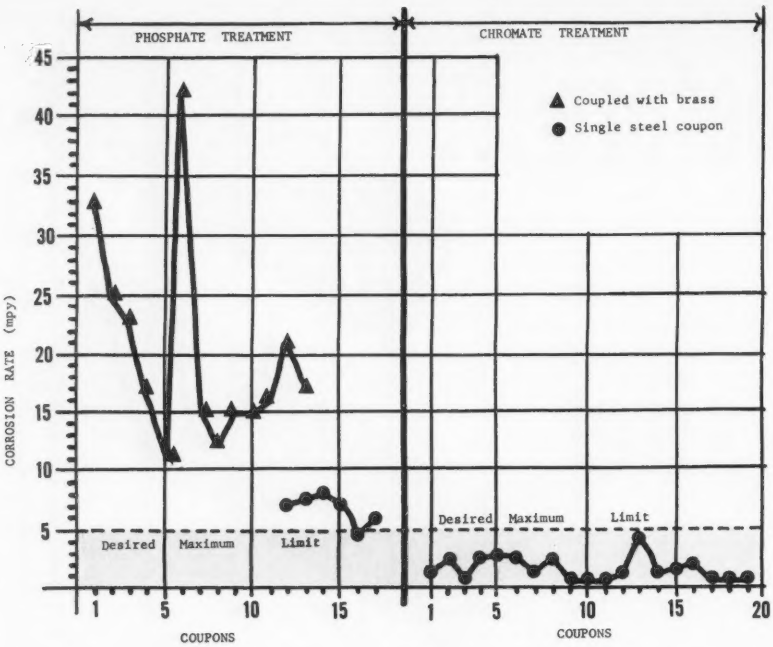


Figure 1—Comparison of coupon corrosion rates with phosphate and chromate water treatments.

Refinery Corrosion—

(Continued From Page 18)

late brass tubes in a carbon steel tube sheet. This procedure led to very high corrosion rates as shown in Figure 1. Installation of single carbon steel coupons were recommended because readings from the couples gave a false indication of the corrosion rate. Corrosion rates on the single coupons dropped considerably, but they remained above the range of 5 mpy set as the maximum corrosion rate.

In January, 1957, while the unit again was down for inspection, condenser shells with water on the shell side were replaced with new shells clad with Type 316 stainless steel. Water treatment could not adequately protect the shells because water velocity was too low to keep the protective film repaired.

In May, 1957, phosphate residuals were increased to a range of 14 to 18 ppm metaphosphate to further reduce the corrosion rates. The pH and MBT ranges were to remain as they were. At this phosphate range, it was difficult to hold the pH at the bottom of the recommended range, which was necessary to keep from precipitating calcium phosphate at the operating temperatures. This remained a problem because the make up water hardness was so high.

Revised Treatment

In September, 1957, use of a proprietary inorganic chromate treatment was started. Recommended chromate residual was 15 to 20 ppm in the recirculating water. Tower water pH range was 6.5 to 7.0. A new type of phosphate treatment also was added to the once-through water for scale protection of the bundles using this stream. The recommended treatment called for an initial dosage of double the normal residual. This was maintained for two days to film the equipment as rapidly as possible. After this period, the treatment residual was allowed to drop to the recommended range of 15 to 20 ppm as CrO_4. The limit on concentration cycles was increased to 3 (determined on total hardness) because a lower phosphate residual was obtained in tower water and calcium phosphate precipitation was no longer considered a problem. Due to the method of introducing the make up, concentrations averaged about 1.7.

At the start of this chromate treatment, reformer operators checked the pH once each shift on a color comparitor. The readings were used only as a check against the pH instrument, not to adjust the instrument. Chromate residual was checked once each shift on a photometer to guide the operator in setting the chromate feeder.

The refinery control laboratory ran checks semi-weekly on chlorides in the make up and recirculating water to control concentration cycles. Daily checks were made electrometrically on the water pH.

The water treatment field engineer during his monthly calls at the refinery analyzed total hardness, calcium hardness, total alkalinity, chlorides, dissolved solids, orthophosphate, chromates, hydrogen sulfide and pH. His analyses were used as a check against various tests run by refinery personnel. He discussed his results with the refinery supervisor in charge of the water treatment and made recommendations concerning necessary treatment. When the unit is down for annual inspection, the field engineer inspects the equipment as a check against results taken from the corrosion coupons.

In the original piping layout, all the once-through water was discharged into the tower as make up, and the tower blowdown consisted of the excess water going into the overflow to the sewer. At the next shutdown some of the once-through water was by-passed to the sewer, and the cycles of concentration were regulated from this point. Typical circulating water analysis where the treatment is the chromate type is given in Table 2. The cycles of concentration were raised to 2.46. Cost of the chromate treatment was less than the previous phosphate treatment even though unit cost of chromate treatment chemicals was higher. All the $Ca_3(PO_4)$ precipitation could not be prevented, but the amount found later in the tower basin showed this to be no great problem.

In the original design, tower blow down was cooled water. This was inefficient. During a shutdown, a by-pass was installed to blow down hot water from the return line before it entered the tower, thereby eliminating the inefficiency.

When MBT was used as an auxiliary to phosphate treatment, the pH recorder operated erratically, caused by the MBT plating out on the cell. The recorder leveled out after the chromate treatment was started.

Materials Deterioration in the Atmosphere

The Mechanism by Which Non-Ferrous Metals Corrode in the Atmosphere by P. M. Aziz and H. P. Godard, Aluminium Laboratories, Ltd., Kingston, Ont.

Mechanisms of Atmospheric Corrosion of Ferrous Metals by C. P. Larrabee, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa.

Principles and Procedures Employed in the Design and Interpretation of Atmospheric Corrosion Tests by H. R. Copson, Research Laboratory, The International Nickel Co., Inc., Bayonne, N. J.

Deterioration of Materials in Polluted Atmospheres by J. E. Yocum, Bay Area Pollution Control District, San Francisco, Cal.

REPRINT PRICES. (Postpaid, except to addresses outside United States, Canada and Mexico, when additional 65 cents for book post registry must be added) Per copy, $2. Ten or more copies to one address, $1. For larger quantities write for quotation. National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas.

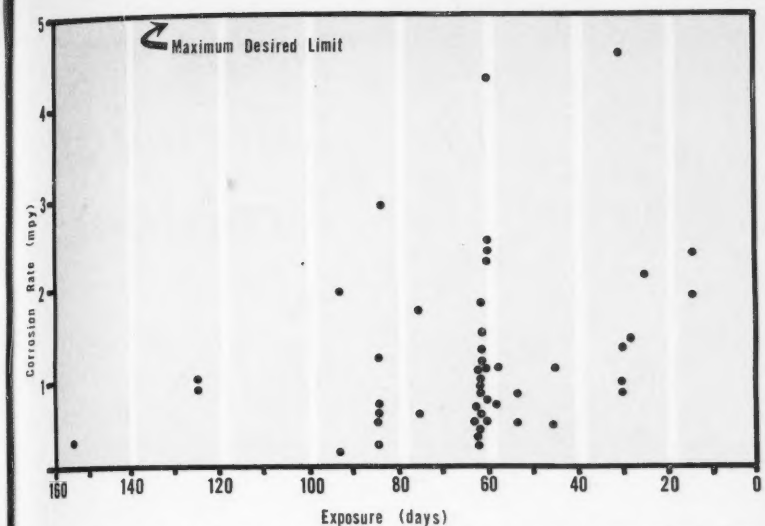


Figure 2—Corrosion rates of 48 coupons exposed for varying periods in a chromate water treatment system.

Tower water became clearer and had an amber color imparted by the chromate. Within two days, formation of the protective film could be detected by its greyish coloration on exposed metallic surfaces.

After the new treatment was in operation for a few days, corrosion coupons were installed. Corrosion rates on the first coupons installed in September for 30-day and 60-day periods varied from 0.5 to 4.3 mpy with an average rate of 1.9 mpy. These coupon rates are given in Figure 1.

Figure 2 shows a plotting of corrosion rates and number of days exposed for coupons used. The range is from 0.4 mpy to 4.6 mpy with an average of about 1.0 mpy. Because corrosion rates of less than 5 mpy are attainable over an extended period, the maximum desired corrosion level may be lowered to 2.0 mpy for all of Standard Oil's recirculating cooling water systems.

In February, 1958, when the reformer was down for a turn around, most of the coolers and condensers were opened for inspection. In general the equipment was in good condition. Some channels and cover plates had an accumulation of deposit; however, an old accumulation probably was layed down during the phosphate treatment. A subsequent analysis showed this deposit to be 58 percent iron oxide (Fe_2O_3) and 21 percent organic. All tubes were clean and coated with a thin protective chromate film. There was no evidence of more than minor corrosion on any of the surfaces exposed to recirculated cooling water.

Some tubes in the rerun overhead condenser were plugged with a very hard deposit analyzed to be 86 percent calcium sulfate ($CaSO_4$). Drilling was necessary to clear the tubes. Because this bundle had not been pulled at the last turn around, most of the deposit probably was layed down before the chromate treatment.

An analysis of tower basin sludge was primarily iron phosphate and calcium phosphate with a fairly high organic content. This analysis was anticipated because the basin had not been cleaned before the chromate treatment was begun.

After the start up of the unit with three concentrations in the tower, the chromate content was 20 to 25 ppm and the pH remained 6.5 to 7.0. The increase to three concentration cycles was possible because piping changes were made during this shutdown.

In March, 1959, the unit was down for a turn around. In general the equipment looked good with little, if any, new pitting corrosion. Again, there was a deposition of iron oxide and phosphate on the channels although not as heavy a coating as noticed at the previous shutdown. All tubes and tube sheets were coated with the chromate protective film. There was a thinning of the carbon steel adjacent to the Monel gasket surfaces, but this galvanic action would not be stopped by water treatment. Bundles cooled with once-through well water were coated with a thin dark scale, but there was no appreciable corrosion under the scale. Corrosion coupons in the circulating water showed an average corrosion rate of about 1.0 mpy.

Microbiological Treatment

The cooling tower was equipped originally with a chlorinator for relatively good control of microbiological growths. However, a growth which chlorine would not kill formed on the tower's distribution deck. This growth was removed occasionally by sweeping the deck during or just before the chlorination period. The chlorinator was operated two days each week, being operated for four hours after a 1 ppm residual was detected in the circulating system. Because of maintenance costs of the chlorinator and chlorine leaks in the piping, organic algaecides were used in the system when the chromate corrosion prevention program was begun. Recommended treatment was two different proprietary compounds: one was a copper naphthenate, the other a mixture of sodium chlorophenates. These algaecides presented no system feeding problem; the required dosage was dumped in at the prescribed time.

The additional cost of organic treatment over chlorine was almost four times that of chlorine. Despite this increased cost and because there was no feeding equipment maintenance, no safety problems, and less manpower required, continued use of the algaecides was considered justified.

CORRODED UNITS

Glaco ends both!

Corrosion prevention is a perplexing problem that's highly individual in nature. As a leading custom applicator of specialized plastic materials, Glaco's experienced staff will determine and apply the exact coating system to solve your particular problem. The thin film coatings of fluorocarbon and other unique plastic resins applied by Glaco, insure outstanding chemical resistance to both inorganic and organic agents — even up to temperatures of 400° F. Wherever you are, Glaco is near with coast-to-coast facilities to handle all your special coating requirements.

GLACO

The Complete Custom-Engineered Coating Service!

INDUSTRIAL COATINGS DIVISION
THE NATIONAL GLACO CHEMICAL CORP.
(A Subsidiary of Ekco Products Co.)
1949 N. Cicero Avenue, Chicago 39, Illinois
© 1960

CM-760

Descriptive Brochure Now Available!

Industrial Coatings Division
The National Glaco Chemical Corp.
1949 N. Cicero Avenue
Chicago 39, Illinois

☐ Please send me a copy of your 12-page, full color brochure on custom-engineered coating service, without obligation. ....

☐ Have a sales engineer call on me.

Name_____

Title_____

Company_____

Address_____

City_____ Zone____ State_____

Figure 1—Failure of vinyl underwater body paint due to poor surface preparation and application.

Some Corrosion Problems in Ships and their solutions*

—Lt. Cmdr. R. S. Capp
U. S. Coast Guard
New Orleans, La.

—B. J. Philibert
Pittsburgh Coke & Chemical Co.
New Orleans, La.

PART 1—Looking at Hard-to-Reach Spaces and Thin-Gauge Hulls

Abstract

Although considerable progress has been made in reducing corrosion of exterior ship hulls and tanks, little progress has been made on superstructure or interior surfaces. The use of thin scantling and thin shelled construction for high speed ships makes the internal corrosion problem more important than ever. Mild steel hulls now generally used must have a coating of high integrity if they are to resist corrosion even when cathodic protection is provided. Problems associated with decks, dissimilar metal fittings, aluminum superstructures, bilges, voids, and other internal areas are discussed. Examples of corrosion damage are reported because of poor coatings. The problems peculiar to space behind fitted instruments and furniture, especially those involving insulation are discussed. How decks corrode under covering presently used is described. 8.9.5.

CORROSION ABOARD ships has been a serious problem for the 100 years since iron and steel construction first became common and probably before that to some extent in connection with fastenings on wooden vessels. While the basic marine environment is worse today than formerly, vessels now are subjected to highly corrosive chemical attack while in most ports in addition to salt water corrosion while underway. The nearly complete shift to welded construction in recent years and the growing use of light weight hulls and superstructures have made corrective measures mandatory. There is a growing awareness of the scope of the problem.

A literature review shows that external hull corrosion below the water line has been the subject of extensive research as also has the problem of hull appendages. However, relatively little has been done about upper decks and deck houses externally. Almost no attention has been paid to internal corrosion except that involving tanks.

Underwater body corrosion, while still costly, is well under control and no really serious conditions are known where an enlightened approach has been used. This is not to indicate the problem is solved; it is relatively under control. To a somewhat lesser extent, this is true also of tank corrosion although the progress here is not so far advanced.

But topside corrosion is another matter entirely. A walk along any waterfront will show almost every vessel in port with men applying paint to hull and superstructure, often even over rust!

As far as internal corrosion in areas other than tanks is concerned, the picture is even bleaker because in many cases the operators are not even aware of it.

These are some of the reasons this article covers briefly, and quite inadequately, underwater body and tank corrosion while it emphasizes those problems of "lesser importance" which add tremendously to the annual maintenance bill. It has been estimated that American industry loses eight billion dollars annually through oxidation and corrosion.[1] Anyone in the marine repair industry will agree that a very large percentage of this is in his field. The damage is so widespread there no longer are problems of "lesser importance."

Different Segments of Problem

In the early days of iron and steel ships the hull was constructed of riveted and bolted shapes and plates. All parts of the structure were turned out by the shipyard's blacksmith shop so no dissimilarity of metals or heat treatment existed. Consonant with the historical conservatism of the ship-building industry and ship designers, a large safety factor was built into the scantlings.

Iron's lack of ductility made it all the more important that the plates and shapes be heavy enough to produce an extremely rigid hull. Because, then, as now, no really exact method existed to compute the forces to which the hull would be subjected, a safety factor usually was added to the safety factor.

When Bessemer and open hearth steels became available for ship construction, they were adopted without any reduction in size. Under these standards extensive corrosion could occur without affecting the safety operation of the vessel.

In the 1890's, after it became apparent that accelerated corrosion of the underwater body and its appendages would be a serious problem, some owners returned to wooden construction for a while. Since then, however, there has been a continued and enlightened approach to controlling underwater corrosion.

It is interesting to note here that while the exterior of the hull was getting full attention, the interior was not even discussed in the literature of that time and for that matter, seldom is today.

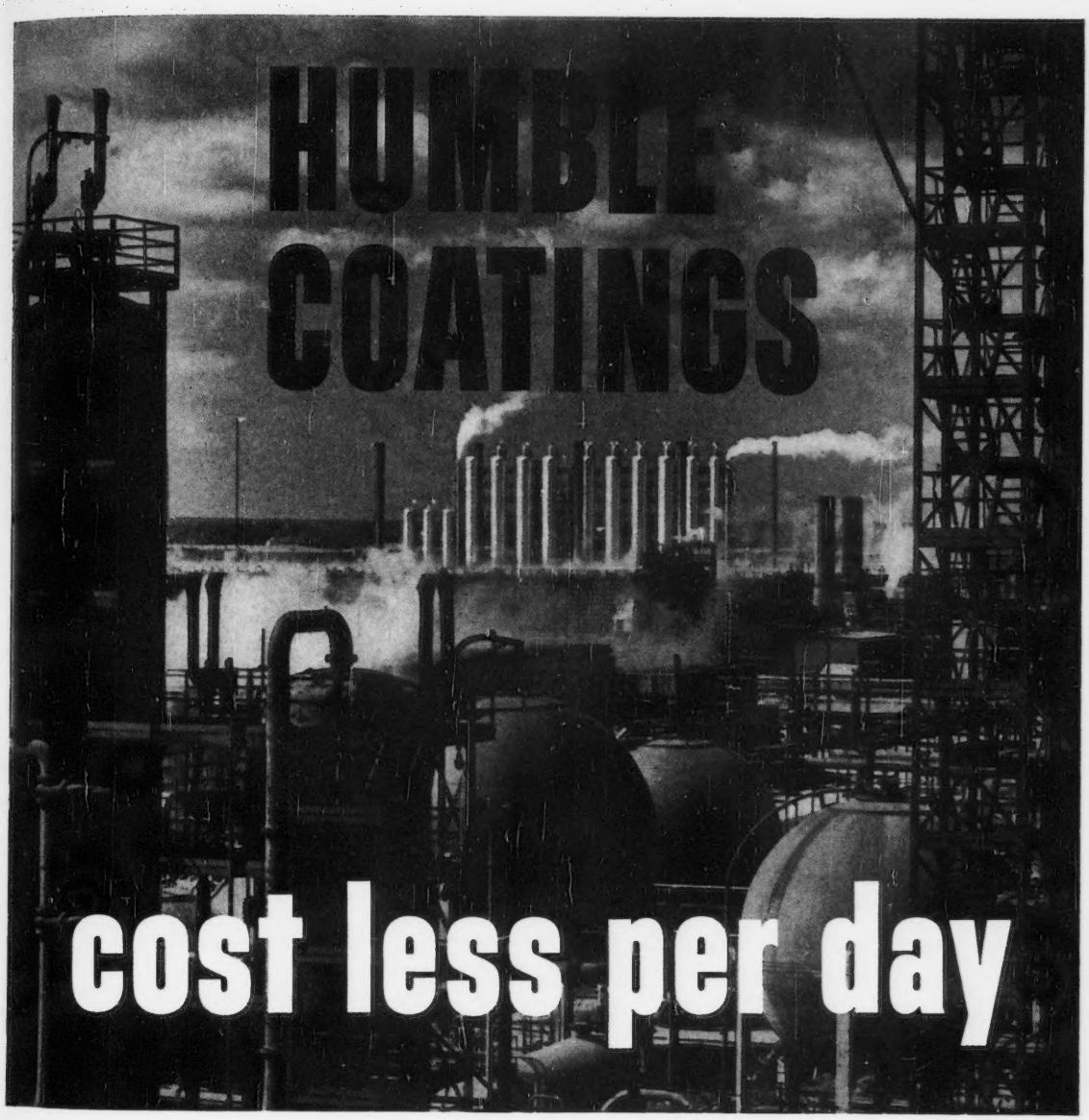
Exterior Areas Above the Water Line

These areas have never received the same attention as the underwater body, probably because damage to them seldom, if ever, results in loss of a vessel. Many operators consider topside corrosion merely an "appearance" problem rather than a structural one.

On this point, the big problem of "operator attitude" is encountered. On most Naval, Coast Guard and merchant vessels, protection of this area is the primary responsibility of the ship's force. There is almost invariably no true understanding of the problem and often a deficiency of the most rudimentary tools to do the job. In the effort

(Continued on Page 24)

★ Revision of a paper titled "Marine Corrosion in Ships—Part 1, Protection of Ship Hulls Against Corrosion—Part 2," presented at a meeting of the Northeast Region Conference, National Association of Corrosion Engineers, Baltimore, Md., October 5-8, 1959.



Humble paints and protective coatings last longer — extend the interval between your repaints by six months to a year. Fewer paint jobs mean savings on paint and labor. Cost per day is that much less.

But this is your big saving: Humble coatings give you better protection — they pay off in longer life for expensive equipment.

Developed to give maximum protection under the severe corrosive conditions in refineries and chemical plants, these continuously improved coatings have been profitably used by industry for over 25 years.

For more information on Humble's complete line of paints and protective coatings call your Humble salesman, or contact Humble Oil & Refining Company, Houston, Texas.

HUMBLE

HUMBLE OIL & REFINING CO.

Life in these excited states...

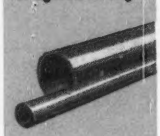
"This, gentlemen, is all that is left of Plant 'B' "

Survival . . . first rule for plastic pipe

Passive resistance . . . that's plastic's survival technique under the onslought of corrosive chemicals. Ace plastic pipe, for instance: inert, impervious, age-less . . . while metals and lesser materials dissolve and crumble. Best for the money anywhere . . . backed by 108 years' experience.

All-purpose rigid PVC. Sched. 40, 80 & 120, ½ to 4". Threaded or socket-weld fittings. Valves ½ to 2". NSF-approved. *Bul. CE-56.*

RIVICLOR for ageless strength



Improved design . . . now 12 gpm. All wetted parts acid-resistant, wear-resistant Ace hard rubber. Finest available. *Bul. CE-55.*

NEW ACE Gear Pump

Flexible poly pipe, ideal for water lines, drains, underground pipe or conduit. Sizes ½ to 2", long coils, NSF-approved for drinking water. *Bul. CE-57.*

SUPPLEX tops in economy

World's best chemical valves . . . at moderate prices. All-plastic, rubber-lined, or all-hard-rubber. ⅛" pet cocks to 24" gate valves.

VALVE HEADQUARTERS

ACE *chemical resistant equipment*
BY AMERICAN HARD RUBBER COMPANY
DIVISION OF AMERACE CORPORATION
ACE ROAD • BUTLER, N.J.

See ACE equipment in Chemical Engineering Catalog

Ship Corrosion –

(Continued From Page 22)

to maintain acceptable appearance, protective coatings often are applied over improperly prepared surfaces and, in some cases, over rust and loose scale.

Another serious problem is the use of fittings made of metals dissimilar to that of the hull. Also, the recent widespread adoption of aluminum superstructure, masts and stacks has further complicated the problem. Very little effort is being made to solve problems created by this unfortunate selection of metals far apart in the galvanic series. A solution will require major re-examination of design, configuration, material selection and coatings applications as well as a re-orientation of operator attitude.

Effective Work Being Done on Tanks

Tanks continue to be a major problem but much effective work is in progress and the literature documenting this work is extensive.[2-6] Since much of the work in this field has been accomplished by members of the National Association of Corrosion Engineers, no discussion of these areas is considered necessary here.

Interior Areas Other Than Tanks

Interior areas other than tanks have received less attention than any of the others and yet contribute heavily to the total cost of maintenance. The extent and seriousness of this problem is seldom realized, even by those in the field because these areas are out of sight, are extremely difficult to inspect and even more difficult to protect. It is true that deterioration in these spaces is more often discovered inadvertently when accomplishing other work, than by purposeful inspection. Most important are bilges, holds, voids, lazarettes and shell plating and structural members hidden by furniture, hull insulation and deck covering. To prevent under-estimating the problem, it is noteworthy that the writer personally has supervised extensive renewal of bottom plating and structure in five ships and numerous small boats in the past two years. In none of these instances did corrosion progress from the outside in.

While much of the following detail is necessarily a summary of personal experience, discussions with other responsible people in the ship maintenance field indicate the conclusions to be valid, especially in the highly corrosive atmosphere of the Gulf of Mexico and its ports.

Protection of Underwater Body

In all except the light weight high speed craft, the basic problem of controlling underwater corrosion is now of manageable proportions. Because of continuous studies on improved hull coatings, particularly in the Navy, present systems if applied properly (and that point cannot be over-emphasized) give excellent adhesion and considerable abrasion resistance.

The intelligent use of zinc anodes of high purity fitted with cast-in steel straps for welded application has assisted materially. Cathodic protection on both active and inactive vessels has progressed from what was a fairly exotic concept 15 years ago to a highly practical and effective system which is complementary to the coating system and promises even more in the future due to recent use of plastics.[7-10]

(Continued on Page 26)

According to Mr. David Greene, of A & G Welding:

"Bitumastic solved our coating problem without delaying our production"

"Part of the reason for the excellent reputation of our swimming pool filters is their long service life," says Mr. Greene, president of A & G Welding and Boiler Co. in South Kearny, N.J. "And protection of the steel interior of these filter tanks against corrosion is an important factor in obtaining this long life," he continues.

A & G tried numerous coatings before selecting Bitumastic® Tank Solution for the job. Some coatings—even more expensive materials—failed due to undercutting; others just took too long to apply and dry, a drawback from the standpoint of maintaining efficient production. Now, tank heads are hand-brushed and the finished, fabricated tank is coated through a port with a specially designed spray gun. The tight, uniform coating film formed by Bitumastic Tank Solution gives long-lasting protection. And, since this coating was specially formulated for potable water applications, it imparts no taste or odor to the pool water processed by the filter.

Just as this Bitumastic coating solved one manufacturer's problem, you will likely find the answer to most corrosion-preventive requirements in one of the ten Bitumastic products. Whether you're coating your plant or your product, Bitumastic coal-tar based protective coatings can help you do it quickly—and less often. Use the coupon for full details. Koppers Company, Inc., Tar Products Division, Pittsburgh 19, Pa. District Offices: Boston, Chicago, Los Angeles, New York, Pittsburgh and Woodward, Ala. In Canada: Koppers Products, Ltd., Toronto.

SEE OUR CATALOG IN SWEET'S
OR WRITE FOR COPY

KOPPERS
BITUMASTIC
COATINGS AND ENAMELS
another fine product of COAL TAR

KOPPERS COMPANY, INC.
Tar Products Division
Dept. 100-G
Pittsburgh 19, Pa.

Gentlemen:
Please send me more information on the Bitumastic family of protective coatings.

Name_____

Firm_____ Title_____

Address_____

City_____ Zone____ State_____

Ship Corrosion—

(Continued From Page 24)

As long as the protective film remains intact and zinc anodes and waster pieces are properly positioned and attached, underwater corrosion is not serious in the first 18 months after undocking. This term coincides reasonably well with the overall average interval between dockings. No matter how good the coating, however, abrasion in the normal course of operation will break the film and make routine dockings for inspection necessary. The normal wear of stern tube bearings, propeller damage, shaft inspection and repair of electronic gear also makes a periodic docking mandatory.

In the case of merchant ships, both the Code of Federal Regulations and the Classification Society Rules require routine dockings and withdrawal and inspection of the shaft. Therefore, any system which gives adequate protection for at least 18 months is likely to prevent serious underwater corrosion. Of course, the system which stays basically intact and requires little or no touch-up at these dockings has a very definite economic advantage over one which requires complete renewal. However, there are so many variables in application technique, adequacy of surface preparation and the temperature and humidity conditions prevailing at the time of application, that the additional first cost of long-lived coatings is not always recovered.

All the above concerns ships with hull plating of ½-inch thickness or greater. With lighter hulls, however, the picture changes radically. Generally speaking, these hulls are also made for relatively high speed operation. Since World War II, numerous hulls of this type have been constructed including those of Naval and Coast Guard patrol craft, off-shore crew boats, pleasure craft and special purpose craft. Because of the shell plating, structural members and all fittings are light in weight, some consideration usually is given in the original design to corrosion resistance.

Many were built with galvanized steel hulls with the weld scars touched up with molten zinc spray or with zinc rich paints after fabrication. While this did reduce shell plate corrosion as long as it remained intact, it introduced so many side effects that it has been all but abandoned. The most critical deficiency is the extreme difficulty of preventing zinc inclusion in welds, both during construction and during repairs. Because these light plate welds always produce austenite and usually have a high percentage of hydrogen (despite the use of low hydrogen rods), the addition of zinc makes a highly brittle weld which is almost certain to fracture.

Some hulls have been fabricated of aluminum; others of low alloy steels and low grade stainless. Each of these hulls has its own set of problems usually connected with properly isolating the dissimilar metals of hull, shafting, rudders, bearings and other appendages and with stress corrosion.[11] They also are economically insupportable, both in first cost and in maintenance costs and usually must be repaired in yards where facilities are available not required for ordinary small craft work.

Mild Steel Is Final Choice

After approximately ten years of experimentation, it has become almost universal practice to use mild steel construction and depend on a coating system and zinc or magnesium anodes to protect the underwater body of small vessels. Ships so constructed require much more frequent docking than larger vessels; six months being usual and a year's interval the maximum. Thus, the underwater protection cost on small craft is much greater relatively than it is on larger vessels. In seeking to reduce this cost, reliance often is placed on a coating system of higher quality than on larger ships in the expectation that protection will be obtained for longer periods.

Unfortunately, most high quality coatings for these applications require reasonably good temperature control, even better humidity control and, above all, first-class surface preparation. In the average shipyard faced with a production schedule, these goals are almost never realized. The vessel obviously is of no value to its owners while sitting on a drydock, so there always is a tendency to apply the coating whatever the temperature and humidity unless there is a veritable deluge or blizzard. Surface preparation is usually good in those areas which are easily accessible, but ranges from fair to poor in the hard to reach areas which are the usual locations of corrosion.

Economic Problem Exists

There is also a very practical economic problem involved. The shipyard will prefer to blast the entire hull at one time, and follow with pretreatment and the primer coat. If the hull is of normal size, this work will span more than standard work day. So the shipyard and the owner are faced with the choice of working overtime, doing the hull in sections (both relatively costly operations) or going as far as possible in one day, then sand-sweeping and completing the coating the next day. Sometimes, in extreme cases, not even sand-sweeping precedes picking up the work the next day.

Of these alternatives, only the first two offer any hope of providing protection, but because they are costly, they are often passed over. From twenty years of practical experience with this problem, it is the writer's opinion that the "straight through-and overtime be damned-method" is the only satisfactory one, particularly if the coating is a vinyl or epoxy. Alkyds are less likely to be adversely affected by delays. Experience also teaches that a high quality coat poorly applied over a poorly prepared surface is an open invitation to extensive corrosion damage of the hull because it gives a false sense of security.

Figure 1 shows removal of a vinyl film which looked good when the vessel was docked but which proved to have very poor adhesion and to cover accelerated underfilm corrosion. As shown in the photograph, when the film was penetrated by a knife it could be pulled loose by hand. Corrosion damage underneath was so extensive some hull inserts were required although the boat was only six months old at this docking.

Other sources of corrosion on light weight underwater bodies are rough welds, badly fitting plates and, above all, electrolytic corrosion due to dissimilar metals.

For reasons beyond the scope of this paper, propellers, shafts, bearings, rud-

(Continued on Page 28)

COKE BREEZE

Backfill for Anodes

Ideally suited for use with anodes. Has a high carbon content and comes in sizes of ⅛-inch x 0 to ⅝ x ⅛ inch. In bulk or sacks. Prices on other sizes on request.

National Carbon Anodes
Magnesium Anodes
Good-All Rectifiers

WHOLESALE COKE COMPANY

PHONE GARDENDALE, ALA.
HEmlock 6-3603

P. O. Box 94 Mt. Olive, Ala.

LET *Coreco* WORK FOR YOU 24 HOURS A DAY TO PROTECT YOUR OFFSHORE EQUIPMENT AGAINST COSTLY CORROSION . . .

Two-fisted Coreco protection pays for itself many times. Whether your problem is better solved by rectifiers or magnesium anodes, our engineers have the knowledge to determine lowest overall installation and operating costs. It costs you nothing to check with Coreco engineers.

Coreco

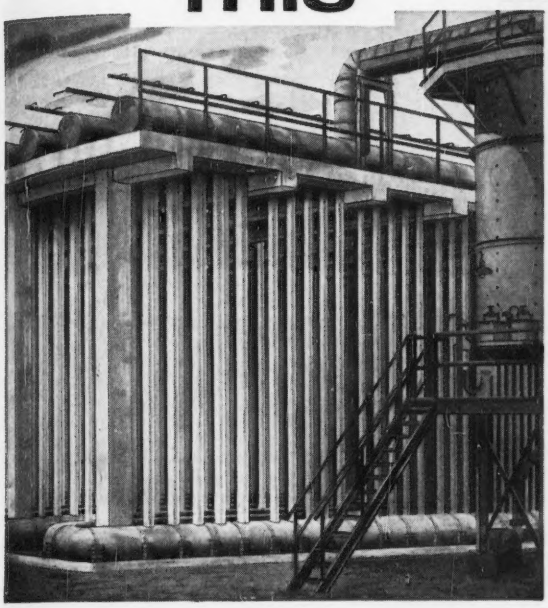
Write or phone today for COSTS • SURVEYS • DESIGNS INSTALLATIONS • MATERIALS

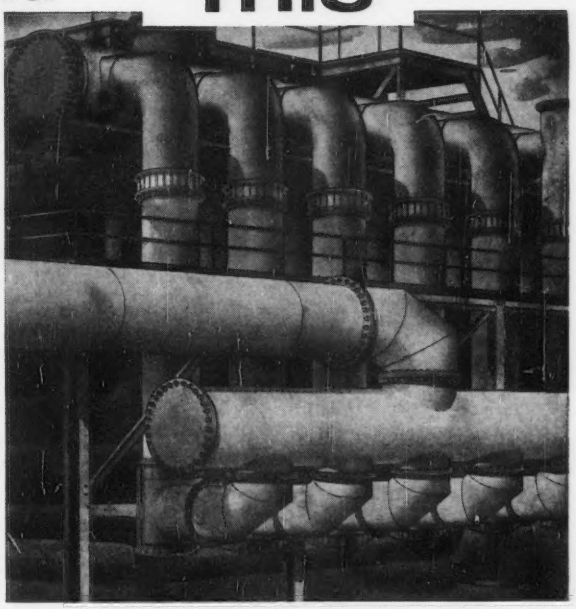
Corrosion Rectifying Co., Inc.

5310 ASHBROOK • MO 7-6659
HOUSTON 36, TEXAS

THE DIFFERENCE BETWEEN

THIS and THIS





is corrosion-resistant

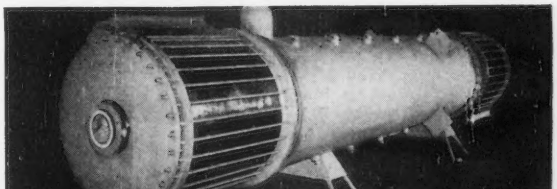
"KARBATE" IMPERVIOUS GRAPHITE HEAT EXCHANGERS!

Today, it doesn't make sense to sacrifice space, money, and minimum downtime by using heat exchangers not having the features of *unsurpassed corrosion-resistance, compactness, and low maintenance of "Karbate" impervious graphite exchangers.* Space was saved, piping simplified, and low maintenance was achieved when the "jungle" of single tube down-draft lead coolers (above left) was replaced by 6 compact "Karbate" shell and tube units (above right).

"Karbate" impervious graphite's high thermal conductivity and complete corrosion-resistance permit these heat exchangers to operate at higher velocities with associated increased heat transfer. This means that "Karbate" units with less surface area can thermally and economically replace larger metal exchangers in which high velocities produce localized accelerated corrosion. In such a case, "Karbate" exchangers with 83% less surface than carbon steel exchangers perform the same cooling job. And, at a total installed cost of approximately $10,000 less than the cost of retubing the corroded carbon steel exchangers with stainless steel tubes.

Actually, "Karbate" units offer unexcelled corrosion resistance at prices, in some instances, up to ⅓ less than many alloy and special metal units in which corrosion is measurable.

If you are considering a new heat exchanger installation, or if you have to replace or add to your present equipment, investigate the advantages of price, excellent corrosion-resistance, and trouble-free performance provided by "Karbate" impervious graphite shell and tube exchangers. For information, write National Carbon Company, Division of Union Carbide Corporation, 270 Park Avenue, New York 17, N. Y. In Canada: Union Carbide Canada Limited, Toronto.



A 45" dia. "Karbate" shell and tube heat exchanger having 685 ⅞" I.D., 1¼" O.D. by 14' long tubes. It has an O.D. area of 3135 square feet.

"National", "Karbate" and "Union Carbide" are registered trade-marks for products of

NATIONAL CARBON COMPANY

UNION CARBIDE

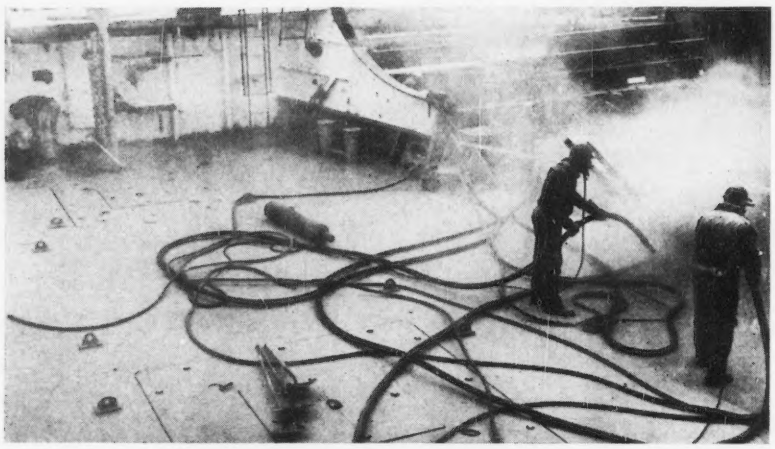


Figure 2—Typical buoy deck being sandblasted before coating is applied.

Ship Corrosion—

(Continued From Page 26)

der posts, and electronic transducers are usually of a metal more noble in the galvanic series than the hull. Designers usually go to great lengths to insulate these from the hull but in the final analysis, the only really effective protection is the coating film—and that only if intact. Because many light weight vessels operate in shallow waters, film abrasion is a constant problem. Once the film is penetrated, accelerated corrosion in the vicinity of these noble metal appendages can be expected.

Above Waterline and Superstructure Problems

As noted earlier, problems in this area usually are more serious than those of underwater body corrosion, both because of the tendency to cover them up and because less attention has been paid to them than to those involving the underwater body.

The gamut of almost every known type of failure is encountered here. The following are listed as typical, but are by no means inclusive.

Figure 2 shows a work deck of a buoy tender. This deck is subjected to loads of buoys, sinkers, chains, and heavy weights of all descriptions. To provide maximum safety for personnel, no weights are worked off the deck which can be slid or dragged across it by the boom. To be useful, it must be so near the water that in rough weather it is always wet. Also, buoys, sinkers and chains when recovered from the water are badly fouled. This fouling is washed off on this deck with a high pressure stream of salt water. Needless to say, any area subjected to this treatment is a problem area. Numerous measures to protect the deck have been tried, but all transfer the problem to surrounding areas unless the protection is extended.

Dissimilar Metal Problem

Another common problem is the practice of designer and operator alike in attaching fittings and fastenings to the deck and superstructure areas made of more noble metal than the basic structure. This practice leads to long-lived fittings and fastenings while the basic vessel rapidly deteriorates. Examples are bronze fire hose valves and strainers, non-ferrous armored cable in steel wireways, chrome plated brass whistles and sirens, stainless steel stanchions with bronze lifelines, etc.

And the operator always will replace worn bolts, screws and other fasteners with non-ferrous or stainless units that can be removed easily. This is a long standing practice and inspection of recent construction indicates the problem is growing more acute as a greater variety of metals become available.

Problem With Aluminum

When, about ten years ago, it became common practice to use aluminum superstructures as a weight saving feature, a whole new area of trouble developed. These troubles can be traced to three sources: The junction, the fasteners, and protective insulators. The junction almost always is perpendicular to the deck. Because this is the wettest possible place and also the hardest possible area to protect, rapid deterioration of the aluminum follows. Fasteners ordinarily are proprietary rivets. Because it is obvious that a cadmium plated rivet will have its coating damaged by driving and because most designers fear aluminum rivets do not have sufficient strength, it has become common practice to use passive stainless steel rivets.

Results Are Calamitous

This use of almost the ultimate in passive materials to join two highly active metals often results in calamity and ultimately could result in a line of free floating fasteners after both the aluminum bulkhead and steel deck have completely disappeared. The standard "protection" of this joint is an insulating polysulfide coating and/or a synthetic rubber gasket between the faying surfaces.

There are at least two serious shortcomings to this type of construction: Neither base metal is protected from the fastener and the exterior sides of the joint at the deck line are not protected at all.

Aluminum superstructures also suffer from the application of commonly used marine fittings of non-ferrous metals and the fastening of armored cable with either ferrous or non-ferrous sheaths. This also is damaging up the mast where there is no abrasion problem.

The primary concern of the marine architect is not corrosion protection. Also, operators and owners demand certain fittings and materials they have come to expect in a vessel. Furthermore, the preoccupation of owners and operators with exterior appearance keeps the designer from relocating the joint areas and using more effective protection. Compatible fittings often are not available and the cost of casting or fabricating them one at a time cannot be justified. Too, the protective coatings industry often has been more interested in selling against competition than in providing adequate protection. Add to all of these the natural conservatism of the shipbuilding industry and reluctance to change classic design concepts and the reason for the present situation is easier to see.

Protection of Interior Areas

Tanks are the only interior areas on which any recent important work seem to have been done.[2, 3, 4]

Bilges, Voids and Inaccessible Interior Spaces

To provide a clear picture of the magnitude of the problem in these areas, the following is necessary. For almost 20 years, one of the co-authors has been directly concerned with shipboard maintenance. In all that time, he has never seen a vessel where exterior hull corrosion had progressed to the point of endangering the vessel. However, he has repeatedly seen vessels whose exterior appearance, underwater body and visible interior regions looked good to excellent but which were found to be both unsafe and unsound after a thorough inspection of voids, bilges and inaccessible interior space.

He has witnessed the renewal of over two million pounds of shell plating, longitudinals, frames and other structural members of which over 95 percent was caused by serious **internal** corrosion. Needless to say, the lighter the scantlings, the more serious this deterioration becomes.

And, despite the seriousness of the problem, these areas actually have received less attention than any other corroding areas aboard ship. There may be objections to this statement. But, it is a fact that most marine operators including the Navy and Coast Guard still specify the same protective coating systems for these spaces as were specified thirty years ago.

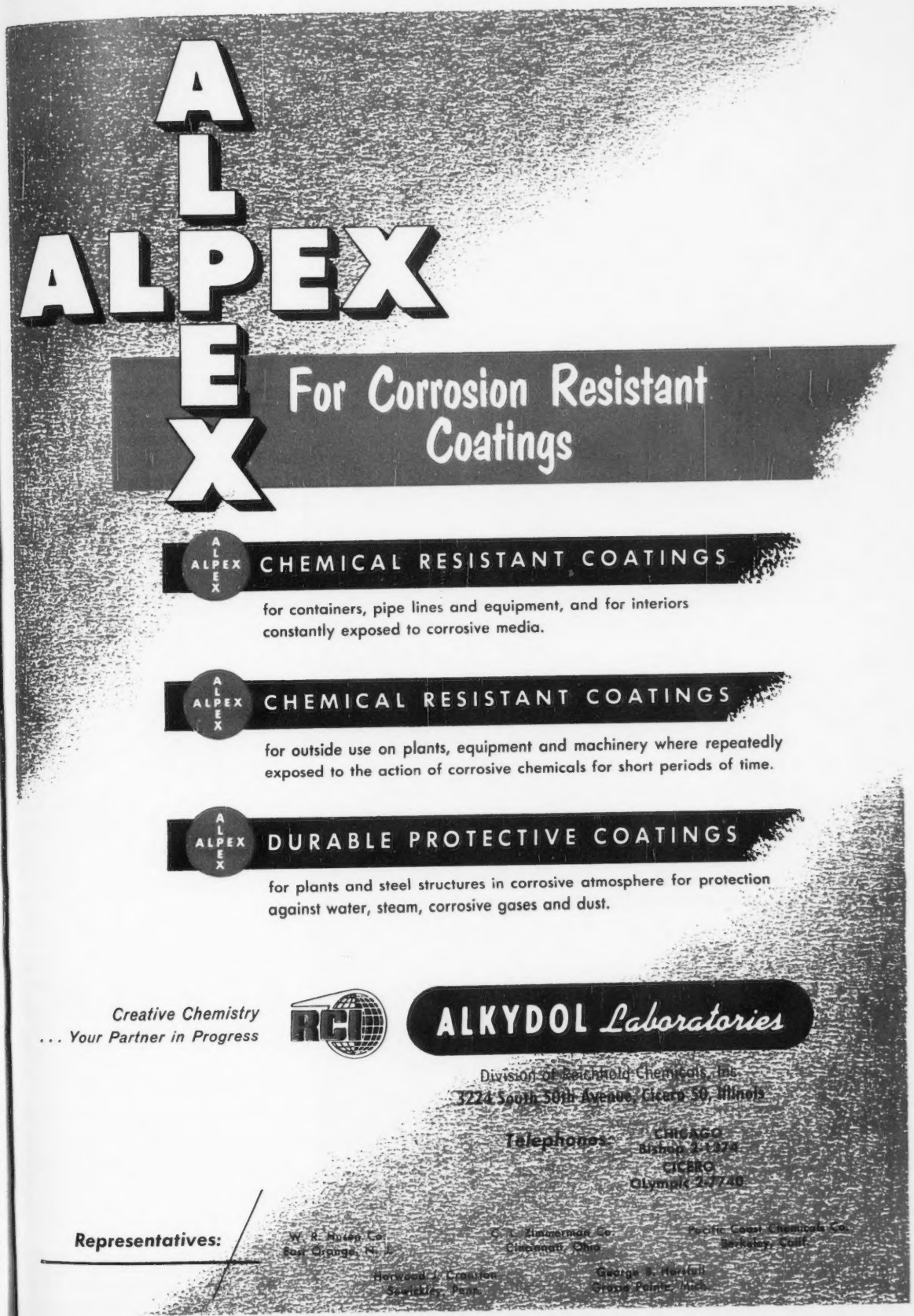
Bilge Areas

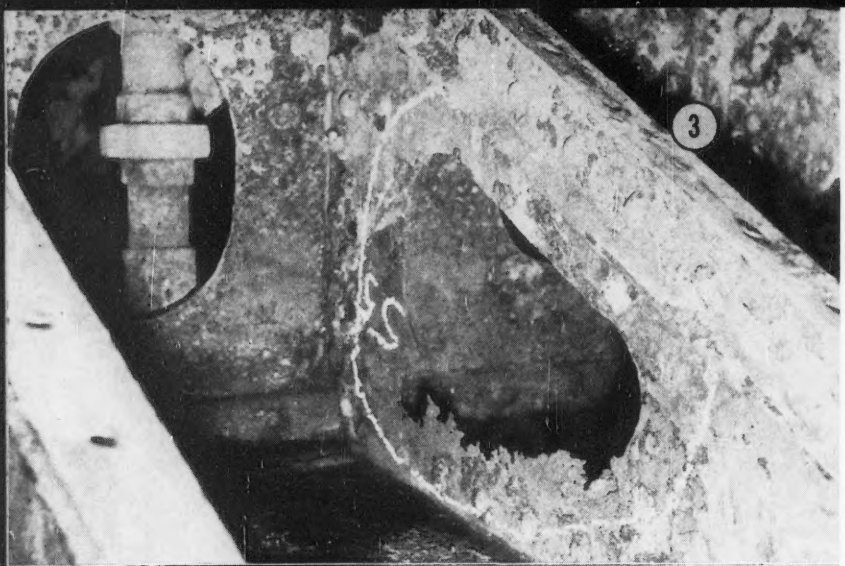
Adequate maintenance of bilges is hindered by the shape and type of the structures, the fact that they are out of sight; that maintenance is considered an operator's job with an operator's priority and because the area almost always is wet.

The shape of the ship hull ordinarily causes the bilge to be a polyhedral shape with design considerations overriding maintenance considerations. Because the hull must withstand severe dynamic loading, it must be relatively rigid, and this necessitates structural keel, web frames, longitudinals and bulkheads. Because the loading is in multiple directions, these members usually are channels, T-bars, flanged plates, angles and bulb angles. Once installed they are extremely difficult to reach with surface preparation or coatings.

Often, a bilge area which at first looks to be in excellent condition, when viewed closely, is found to be in a very advanced state of deterioration. Drain-

(Continued on Page 30)


ALPEX
For Corrosion Resistant Coatings
ALPEX CHEMICAL RESISTANT COATINGS
for containers, pipe lines and equipment, and for interiors constantly exposed to corrosive media.
ALPEX CHEMICAL RESISTANT COATINGS
for outside use on plants, equipment and machinery where repeatedly exposed to the action of corrosive chemicals for short periods of time.
ALPEX DURABLE PROTECTIVE COATINGS
for plants and steel structures in corrosive atmosphere for protection against water, steam, corrosive gases and dust.
Creative Chemistry ... Your Partner in Progress
RCI
ALKYDOL Laboratories
Division of Reichhold Chemicals, Inc.
3224 South 50th Avenue, Cicero 50, Illinois
Telephones: CHICAGO Bishop 4-1274 CICERO Olympic 2-7740
Representatives:
W. R. Hutton Co. East Orange, N. J.
C. L. Zimmerman Co. Cincinnati, Ohio
Pacific Coast Chemicals Co. Berkeley, Calif.
Harwood J. Creation Sewickley, Penn.
George B. Hartzell Grosse Pointe, Mich.



Ship Corrosion –

(Continued From Page 28)

age ordinarily is provided by limber holes through structural members to an eductor foot valve or bilge pump suction strainer. Trim of the ship is not constant so drainage changes with the motion of the vessel and with its loading and often the drainage suction is not located advantageously for the conditions existing at the time of pumping. Some water always remains unless wiped up by hand or scooped out because there must be some clearance between the eductor foot valve or bilge pump suction foot valve. Also, salt water piping systems ordinarily are copper-nickel or other nonferrous material for longer life. If the foot valve is non-ferrous and is close to the shell, as soon as salt water reaches the bottom of the foot valve a galvanic couple is completed and serious deterioration of the shell plating occurs under it.

This interior area is completely below the water line. Except in the unlikely event the water temperature is at or very near the interior ambient temperature, condensation in the area is very heavy.

Action on Problem Is Postponed

Such conditions are not conducive to effective surface preparation and coatings application, so, many operators repeatedly report "we can't do anything about that until we get in drydock." Then, while the vessel is in drydock, higher priority items (at least to the operator's mind) take precedence and the deterioration accelerates. Figures 3, 4 and 5 show the results of this procrastination and ineffective protection. The operator is under considerable pressure to maintain a "presentable" top side appearance. Because his top side rapidly deteriorates he puts available manpower on that which can be seen and treats the bilges as "out of sight and out of mind." He has some justification in this feeling, too, because new and improved maintenance materials and methods are frequently offered for underwater body and top side areas, while the same old red lead system remains standard for bilges.

Voids are small, usually sealed compartments normally used to isolate fuel tanks from water tanks, water tanks from ship's shell, etc. They are often very deep and narrow. Normal access is a bolted handhole plate. Because removal of this plate is very time consuming, voids are almost never inspected unless it is suspected that an adjoining tank is leaking. Because these compartments are completely out of sight, any effective coating system would be useful regardless of appearance. Yet vessels are built today with voids coated with a wash primer and oil based air drying red lead. They usually are seen again when the plating is renewed.

Inaccessible Interior Spaces Above the Hold

In many ways, inaccessible areas above the hold are the most insidious of all. They are so close to areas used daily and are so taken for granted that real inspection is seldom made until the supporting structure is severely dam-

(Continued on Page 32)

Figure 3—Deteriorated web frames in bilges.
Figure 4—Deteriorated shell, bounding bars, sight edges and frames.
Figure 5—Deteriorated frames, sight edges and structure.

FACT: In salt water tests 4-D Wrought Iron proves 39% to 44% more corrosion-resistant than A-53 Steel

The fact stated above is the result of recently completed corrosion tests conducted at A. M. Byers Company Laboratories.

Measurements showed A-53 Steel weight loss to be 39% greater than 4-D Wrought Iron over the 12-month period. In addition to this substantial difference in weight loss, 4-D Wrought Iron did not exhibit pitting. After only three months, pitting appeared on the steel. In the final months of the test, pits on steel had expanded and consolidated until they appeared as drastically thinned areas.

In this test, exposed coupon ends and edges comprised as much as 20% of the total coupon area. Under actual service conditions, however, ends and edges are not exposed or comprise but a minute fraction of the total exposed surface.

Since wrought iron displays directional properties with regard to corrosion-resistance, a corollary 9-month test was conducted with a coating on the edges and ends of all test coupons, steel and wrought iron. *This* test showed 44% greater corrosion-resistance for 4-D Wrought Iron over A-53 Steel. Like the 12-month test, results substantiate 4-D Wrought Iron's corrosion-resistance superiority over steel.

TEST CONDITIONS

Test medium:	3% sodium chloride solution	Coupon size:	1″ x 2″ x ⅛″ and ¼″
Test temperature:	68° to 75°F. (average: 70°F)	Coupon preparation:	Solvent degreasing and polishing on belt grinder using 100-grit carborundum belts
pH:	7.8		
Aeration rate:	3400 cc/min±10%		
Solution volume:	32 liters changed three times each week	Test period:	1. One year 2. Nine months

SUMMARY

The results of both salt water tests establish 4-D Wrought Iron's superiority over A-53 Steel in corrosion-resistance. These results are verified by hundreds of installations where corrosion is a constant problem; and, where wrought iron has performed satisfactorily for years at low cost per year of service. Write for complete test report. A. M. Byers Company, Engineering Service Department, Clark Building, Pittsburgh 22, Pennsylvania.

BYERS 4-D WROUGHT IRON
TUBULAR AND FLAT ROLLED PRODUCTS

Ship Corrosion—

(Continued From Page 30)

aged. In most ships they cannot be inspected without costly destruction of hull insulation, built-in furniture and removal of equipment, so that a calculated risk becomes a substitute for sound economics.

It must be understood that the living areas, galleys, mess decks, ship control spaces, etc., are, like the bilge areas, neither square nor rectangular but necessarily follow the shape of the ship hull.

On the other hand, bunks, wardrobes, tables and chairs and various electronic equipment usually are of conventional shapes. Because space is always at premium, these units usually have to be placed near the shell or bulkheads. The irregular shape of the hull leaves open spaces inaccessible to cleaning which, if not covered with sheathing or fitted boundaries, would become receptacles of refuse and trash. Therefore, it is normally the practice to fair these items of furniture and fixtures into the ship's shell and to the bulkheads. These fairing pieces often are austenitic stainless steel plates. This obviously leaves a void space between the built-in furniture and the shell which favors deterioration almost immediately.

To use available space, officers' berths (and most crews' berths on merchant vessels) are fitted with two storage drawers underneath so the berth fixture appears closed completely to the deck. Even with the drawers removed, the vertical clearance is so small and the horizontal distance so great no effective deck maintenance can be performed without removing the bunk.

Moreover, the deck may be a tank top so that rapid deterioration takes place on both sides of the plate. These are examples of a problem which has endless ramifications.

Figure 6—Bulkhead deterioration found under hull insulation.

Hull Insulation Damage Severe

One of the greatest single causes of corrosion of vessel interiors is the unseen damage under hull insulation. Ship hull thermal insulation must provide maximum resistance to heat and cold in a thin covering of very light weight. It must also retard fire and have reasonable immunity to mechanical damage. Resistance to vapor transmission is desired after considering these foregoing requirements.

Although cork sheets formerly were used (and still are in icebreakers and other Arctic vessels) because of their superior thermal properties their susceptibility to fire has virtually ruled them out. Locations where condensation protection rather than thermal insulation is required often are covered with expanded vermiculite if appearance is not a consideration. Well over 95 percent of all hull thermal insulation is fiberglas board with an inner face of hardened and treated fibrous glass cloth. Although this is a highly fire retardant thermal barrier which is non-corrosive and vermin proof, it is a very poor vapor barrier. Also the fittings used to secure it are not corrosion resistant. It also is expensive to install, requiring laborious cutting and fitting, spot welding of studs for retainers and maximum surface preparation for the adhesive. The only real protection for the shell plating behind it is a fairly effective corrosion resisting adhesive. Because of the expense of renewal, sections are very rarely cropped out for inspection of the hull plating.

Normally, insulation is removed from the shell only for correction of mechanical damage to the insulation batt itself or when it becomes waterlogged and hangs free on its studs from the shell or overhead. In almost every case when it hangs free (which incidentally is quite common) extensive corrosion of the steel or aluminum which occurs underneath requires large scale renewals. Figure 6 shows a longitudinal stiffner completely deteriorated in an area which came to light only because of the need to renew insulation.

Decks Corrode Under Coverings

A similar problem is that of steel deck corrosion and deterioration under deck coverings. Among a wide variety of deck coverings, none is probably best for each purpose but represents a compromise for an effective covering with acceptable weight and fire-retardancy characteristic. Generally, these are nonslip trowel-on coverings of mastic and garnet, rubber terrazzo in showers and wet spaces, cloth particle pressure sensitive treads, vinyl asbestos tile in living spaces, quarry tile in galleys and rubber matting in front of switchboards.

As can be seen from this list, all except the rubber matting (which is simply laid down) depend on the adhesive, the grout, or the top coat sealer to prevent water entering between the steel deck and its covering. This will be true only when first-rate workmanship and materials are used for application followed by careful inspection and maintenance by the ship's force. Because this combination seldom occurs, deterioration of steel decks under the covering, particularly in washrooms, showers and galleys is common.

J. M. Van Orden, terminals manager of Matson Steamship Co., said at a meeting of naval architects: "It is my considered opinion that the naval architect and designer must keep one question in mind at all times when designing a vessel and that is, 'Will this item be easy to maintain or will it require constant replacement; or will it require continual expenditure of labor and money to keep it in efficient and safe condition?'"

Because the naval architect is in such a rapidly changing field and because his

(Continued on Page 34)

Corrosion Control of Ships

1. Owners and operators must acknowledge the existence of the corrosion problem which grows more severe with the trend to lighter scantling construction.

2. A good job while the ship is on the ways may cost a fraction of the cost of doing the job over and over again in drydock.

3. A "good job" results only from tight specifications requiring effective methods and the best materials under continuing, disciplined supervision and rigid inspection.

4. It must be recognized that part of the ship's environment, the sea, is an electrolyte. If there are dissimilar metals in the structure, there will be corrosion.

5. The best possible protective coating, applied in the best possible way, with adequate cathodic protection and best protective practices can save many dollars.

6. Many new "specialized" materials of construction are needed to meet today's design demands, such as the following:

a. A light weight, resilient, flexible, vapor-sealing thermal insulation material for interior decks that can be overlayed with tile as flooring.

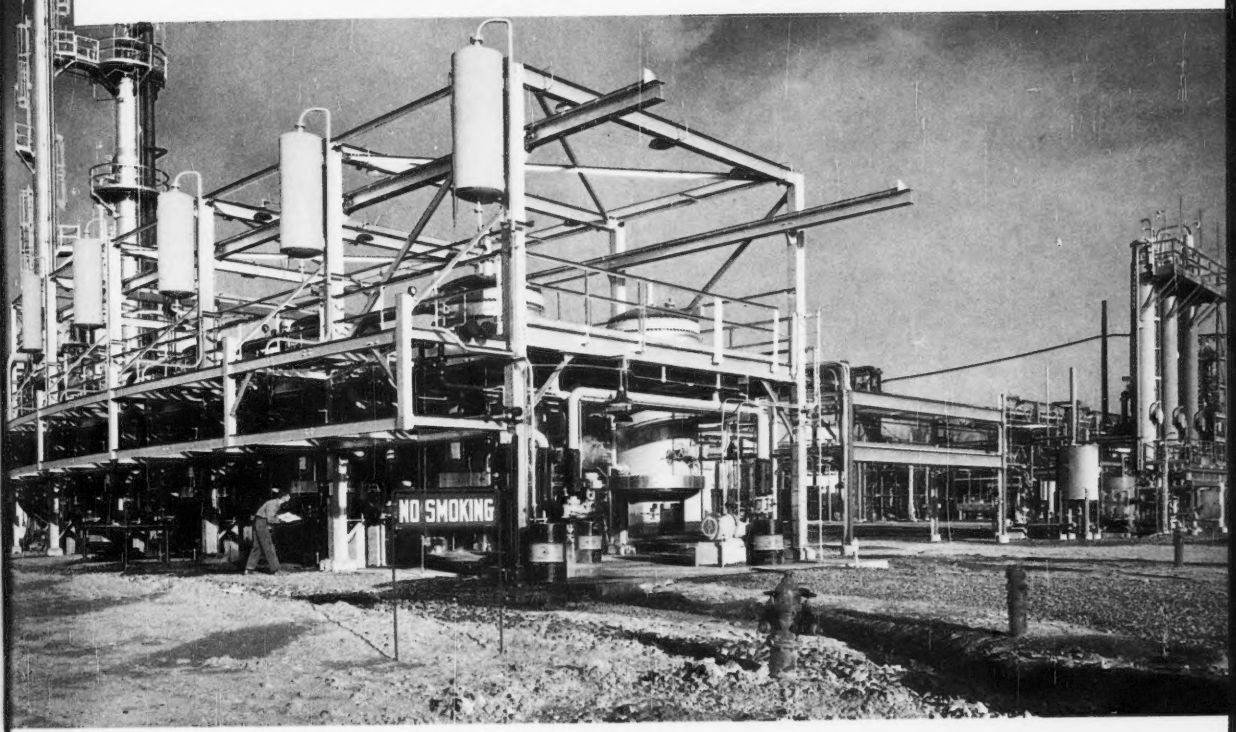
b. A light weight, high strength, sound dampening material which is a complete vapor-seal and independent of adhesives.

c. A metal filled putty for use as a fairing compound which retains resilience.

d. Materials for special uses which have sufficient strength, abrasion resistance and adequate resilience as well as non-skid properties for deck areas subjected to extremely severe service. These materials must be corrosion resistant.

CORROSION PROTECTION

In Depth . . . With Color!



Wherever your plant and equipment are subject to critical acid, alkali or solvent exposures even at elevated temperatures, high humidity, severe weathering — or any combination of these — one of Truscon's corrosion control systems will provide maximum protection at lowest cost per square foot per year.

Truscon will also provide guidance in proper surface preparation, coating application, and inspection. For a detailed, written specification on protection of steel, iron, aluminum, concrete, and other surfaces, call the Truscon branch nearest you, or write Truscon Laboratories for specific information.

TRUSCON *Laboratories*

Resists the Penetration of Water — TRUSCON

Industrial Maintenance Division of Devoe & Raynolds Co., Inc. • Detroit 11, Michigan

Ship Corrosion—

(Continued From Page 32)

first interest seldom is the corrosion problems, he often overlooks those very areas where major reduction of hull maintenance expense could be accomplished easily. For example, the standard requirement for primers in all the interior areas discussed is still red lead for steel and zinc chromate for aluminum. Only when ship and boat designers know with certainty which coatings actually are an improvement, and only when information on these improved coatings is presented fully, including cost data, will the marine field begin to have more effective protective measures. Of course, protective coatings alone are not enough. Materials selection, design factors and more effective day-to-day maintenance are continuing urgent needs.

References

1. Harrison. Rust—The Implacable Enemy. *Journ American Society of Naval Engineers,* November, 1956.
2. Symposium on Control of Internal Corrosion in Tankers. *Trans SNAME,* 1952.
3. Logan. Corrosion Control in Tankers. *Shipbuilder and Marine Engine Builder,* April, 1958.
4. Bannerman. A Structural Approach to Problem of Corrosion in Tankers. *Trans SNAME,* 1954.
5. Pfield. A Shipbuilder Looks at Corrosion. odes. *Trans SNAME,* 1953.
6. Dorey. Non-Ferrous Metals and Marine Engineering. *Journ Inst Metals,* July, 1954.
7. Graham, Cook and Preiser. Cathodic Protection in the U. S. Navy. *Trans SNAME,* 1956.
8. Carter and Crennell. Cathodic Protection of Ships Against Sea Water Corrosion. *Shipbuilder and Marine Engine Builder,* July, 1955.
9. Francis. Zinc Anode Protection System on USS Wahoo. *Journ Bureau of Ships,* April, 1959.
10. Preiser and Stander. Applications of Plastics in Marine Cathodic Protection Systems. *Journ ASNE,* August, 1956.
11. Williams and Eckel. Stress Corrosion of Austenitic Stainless Steels in High Temperature Waters. *Journ ASNE,* February, 1956.
12. Harvey and Streever. Electrolytic Corrosion Inhibiting and Cleaning With Energized Anodes. *Trans SNAME,* 1953.
13. Symposium on Ship Operation. *Trans SNAME,* 1955.

Figure 1—Deteriorated steel found under an excellent appearing oil based, air drying paint.

Abstract

Little change has been made in the coatings used on ships in 50 years. Extensive surveys recently made showed heavy damage suffered from corrosion of internal members of ships because of improper coatings. Reasons for poor painting of ships' insides are given.

Current high-speed, light scantling ships do not have the safety factor formerly available in heavier construction, so a closer attention to coating integrity is needed if severe damage is not to be suffered. Some examples of recent welded ship hull construction are given, with reasons for the poor performance of conventional coatings.

New coatings, especially mastics, offer considerable advantage for interior surfaces subject to stress and movement and damage from salt water and condensation. Examples of effective coating practice are given. A list of reasons for closer attention to ship corrosion problems is given. Some needed new materials are defined. 8.9.5

PART 2—Coating Systems Suitable for Thin-Scantling Construction

SHIP HULL corrosion is one of the most generally recognized afflictions of the marine industry today. For over 60 years there has been tacit acceptance of corrosion with little effort to alleviate it. The comparatively recent change to lighter scantling construction and higher speeds makes it urgent that this attitude be changed.

Formerly, the very substantial safety factors resulting from the generous proportioning of structural members made the possibility of disaster remote. Current designs, however, which emphasize lightness, fleetness and the ultimate in maneuverability, have margins of safety reduced to the minimum. No longer can the ship owner depend upon the generous safety factors provided by the architect. He must now provide some means of preserving the integrity of the ship at or near the level of its original strength.

The solution is adequate protection through effective surface protection and isolation and, wherever possible, the use of cathodic protection.

Little Change in 50 Years

To a surprisingly great extent, many areas of today's finest ships are being protected in exactly the same way common 50 or more years ago.

The coating required for underwater body protection seems a lot simpler than it really is. Conventional hull coatings have traditionally consisted of a number of coats of anti-corrosive paint overcoated with anti-fouling. These have a limited useful life at the end of which it is necessary to renew the anti-fouling. On high speed passenger and merchant ships a fouled bottom results in a reduction of speed of 25 percent and increased fuel consumption of 50 percent. Profitable operation dictates a drydocking and renewal of anti-fouling coatings long before fouling becomes this extensive.

Aside from the fact that the optimum treatment of ship bottoms is not yet standard practice, other areas of the ship are of greater concern. These are the ship internals, decks and appurtenances where today's design does not afford excess material for a safety factor.

Damage Found in Survey

Recently, an extensive survey of military and commercial marine craft showed severe damage frequently unknown to the officers of the ships who, obviously, spend little time crawling through bilge areas with a peening hammer.

Figure 1 shows an area where a colorful oleoresinous paint appeared to have the situation well in hand. A few blows with the peening hammer broke away the scale underlying the paint, disclosing the heavy rust underneath. In some instances, the brightly colored covering paints in bilge areas were dry only on the surface and appeared to be integral with the steel. Hammer blows sometimes disclosed that only the rust scale was supporting the paint and that the structure underneath was actually perforated by rust.

Why Paint Jobs Are Poor

Most construction or repair yards would be very happy if they could protect the entire ship from one bucket of paint. It would simplify their job enormously. Painting usually is something of a nuisance to people whose principal interest is the fabrication of heavy structural elements. Furthermore, at best, it is a difficult job and usually not a highly profitable one.

This being the case, it certainly is incumbent on designers and owners to require proper painting and provide sufficient funds to get adequate protective coating systems; and to insure that this work be well done, provide adequate supervision and inspection of coating application which is not a primary interest of the contractors.

The trend to lighter scantlings makes the problem more pressing. Shell plates often are so light that continuous welding of members to plates is out of the question, so discontinuous or staggered welding is used. This produces many new gaps, crevices, discontinuities and irregularities which did not exist when members were drawn reasonably tightly together by riveted construction. And this occurs in a vessel which, because of its lighter construction, will flex more than those built the older way.

Thin Film Coatings Inadequate

In the wetted, internal areas of the ship, thin film coatings of the past were

(Continued on Page 38)

a wide range of
MAINTENANCE COATINGS
that will save you money!

What do *your* corrosion conditions require? This, in brief, is Carboline's approach to *each* maintenance problem: a service-proven coating engineered to a specific condition.

From our broad line of experienced maintenance coatings, we have a separate, correct system to match each condition—not one or two "cure-all" systems to fit *all* environments. It is this engineering approach that reduces maintenance costs and assures maximum economy.

Carboline coatings are higher in solids content, which produces greater film build-up and requires fewer coats—reducing labor costs. Superior quality results in longer life and requires fewer recoating cycles—again reducing labor costs. That's why Carboline coatings are *in*expensive and give you better protection, too.

May we have the opportunity to bid your next job? We'll prove we can reduce your maintenance costs.

WRITE TODAY, meanwhile, for Maintenance Chart No. 5 with complete details on 17 different maintenance systems. Also, see our Catalog in CEC, pages 911-914.

6005

carboline COMPANY

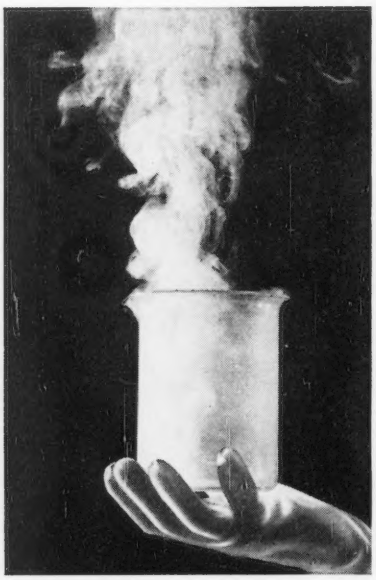
32-A Hanley Industrial Ct., St. Louis 17, Mo.

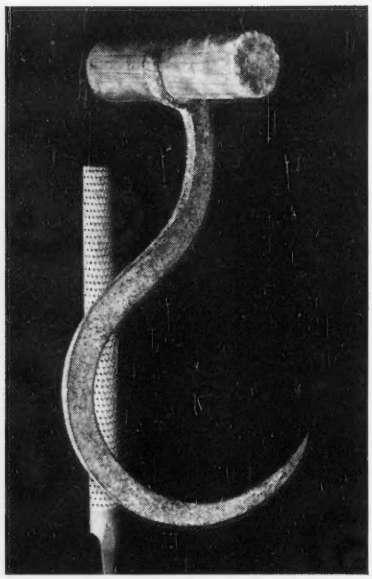
Sales engineers in principal cities. Consult your telephone directory.

MAINTENANCE COATINGS WITH EXPERIENCE

ENJAY BUTYL

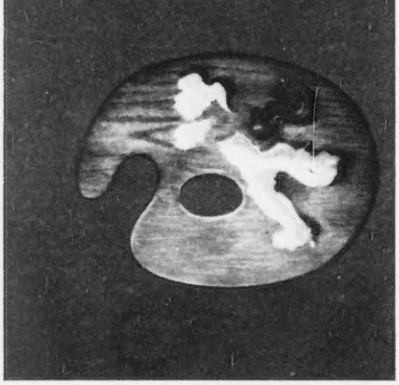
IS TOPS IN ALL-'ROUND P





RESISTANCE TO CHEMICALS

Enjay Butyl, because of its unique and extremely low degree of unsaturation, offers excellent resistance to corrosive chemicals. The preferred rubber for tank linings, hose, seals, gaskets and other applications where exacting chemical resistance is required.



VIVID COLORS

Enjay Butyl requires no additives for quality coloring over a wide range of hues. Famous for colorability and smooth finishes, Butyl has been successfully plastic coated for special applications.

RESISTANCE TO TEAR AND ABRASION

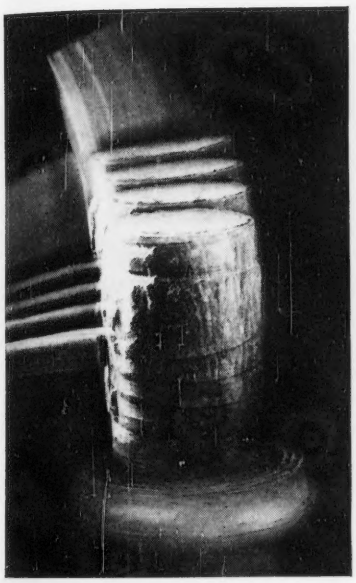
Enjay Butyl offers the highest aged tear strength of any rubber . . . even after long exposure to ozone and heat! Its inherent toughness resists abrasive wear, in such applications as tires, conveyer belts, hose and other mechanical goods.

RESISTANCE TO SUN-LIGHT AND WEATHERING

Enjay Butyl has proven its resistance to ultra-violet light, ozone, oxidation, moisture and mildew. Increases life of products such as weatherstrips, garden hose, wading pools and automotive parts.

RUBBER

PERFORMANCE



DAMPING PROPERTIES

Enjay Butyl absorbs shock and vibrational energy more completely than any other rubber. Resiliency can be varied in compounding and processing. Butyl is ideal for axle and body bumpers, motor mounts and sound-deadening applications.

IMPERMEABILITY TO GASES AND MOISTURE

Enjay Butyl is tops in impermeability to gases and moisture . . . retains air pressure 8 times better than natural rubber. Outperforms other rubbers in such application as inner tubes, jar and bottle seals, hoses and inflatable goods.

ELECTRICAL RESISTANCE

Enjay Butyl tops all vulcanizable rubbers in electrical and dielectric properties . . . in resistance to corona and ozone breakdown and water absorption. Its high dielectric strength insures against electric breakdown under normal or surge voltage. Its heat resistance permits higher current flow for a given conductor size.

The outstanding properties of Butyl Rubber create new horizons for the designer, and offer to manufacturers an opportunity to utilize the qualities of rubber in applications never before possible. The unique properties of Butyl have led to vast improvement in many existing products. Technical skills will open the way to countless new uses.

Butyl is the "idea" rubber with uses stretching as far as the imagination can reach. We'll be glad to tell you all about it. Just contact the nearest Enjay office.

EXCITING NEW PRODUCTS THROUGH PETRO-CHEMISTRY

ENJAY CHEMICAL COMPANY

A DIVISION OF HUMBLE OIL & REFINING COMPANY

HOME OFFICE: 15 West 51st Street, New York 19, N. Y. OTHER OFFICES: Akron • Boston • Charlotte • Chicago • Detroit • Houston • Los Angeles • New Orleans • Tulsa

ENJAY® BUTYL

Ship Corrosion—

(Continued From Page 34)

inadequate to protect the fairly tight construction of that time. Now, with more gaps than ever between members, the problem is worse. Also, the probability of greater and higher frequency hull vibrations is an added complicating factor.

It is mistakenly believed that ships in sea water are exposed to salt solutions on areas other than the underwater body only a comparatively small part of the time. The truth is the underwater body is the only part continuously exposed only to a dilute salt solution. Other parts of the ship are exposed to salt brine solutions which are, at times, considerably more aggressive. Salt, deposited on the decks by spray, from washing down, carried on by cargo or by foot traffic, is carried to all parts of the ship. As the water evaporates, the salt increases in concentration to the point of crystallization and remains behind to be wetted down by condensation, precipitation or leakage. Natural sea water in contact with the underwater body may be much less corrosive.

In areas such as the lazarette, bilges, holds and the chain locker many different kinds of foreign matter also may be introduced to contribute organic as well as inorganic acids directly or through decomposition.

Problems inherent in these exposures are being recognized. In a recent Value Engineering Meeting, after much discussion, a conclusion was reached which should be more widely accepted.[1] There is only one real opportunity to coat such areas as bilges, lazarettes, overheads in holds, etc. This is when the ship is new.

Ship's Hull Is Flexible

A ship appears to be a fairly rigid structure, and at rest, this is approximately true. But, under operating conditions, especially in bad weather, this is far from the case. In even moderate seas, the hull of the ship is like a living thing as it heels from side to side, pitching and pounding. Those who have listened to the sounds in the hold of a ship in rough seas will readily appreciate this condition.

While the integrity and stability of the ship structure usually are not impaired by such service, the integrity of a conventional, old time protective coating system is sorely tried. In Figure 2 the angle bracket in the lower right hand corner still has lots of metal under the rust which is under the surface coating. Now, note the garboard strake plate replacement and the plate reinforcement of the frame in the middleground. There are openings between the frame and hull plate in the spaces between welding "stitches," a gap at the left end of the plate and rough edges and knobs on the welds themselves, all difficult, if not impossible, to protect with thin film coatings. There also is a gap between the replacement longitudinal at the left margin and hull. Visualize the motion which takes place here when the craft pounds and corkscrews in a heavy sea.

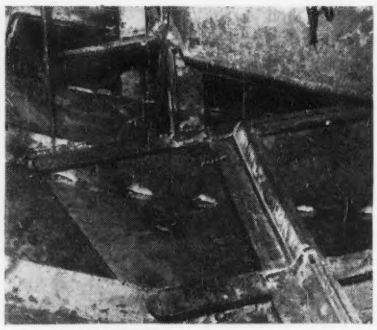


Figure 2—Intermittent welding requiring a heavy bodied coating for protection.

Good New Coatings Developed

Alkyd resins, vinyls, catalyzed epoxies, epoxy modified oleoresinous materials, pigmented phenolics and others all have made contributions to progress in marine coatings. A comparative newcomer, the coal tar epoxy, is now making a further important contribution by doing many things the others were unable to do.

Protection of the underwater body of ships in normal service has greatly improved, due to the comparatively short interval permitted by regulatory bodies between dockings which makes newly developed protective coating systems used with cathodic protection a partial solution of the hull corrosion problems. Continuing progress is being made.

Some craft, however, work under conditions which demand protection better than can be secured from conventional systems. These include freighters, work boats, barges, towing vessels, oil scows, dredges, military craft, etc., which work in Gulf areas, in the Mississippi Delta, into and out of shallow seaports and harbors and have abrasion problems beyond the protective ability of conventional systems. Others, while adequately protected over most of their area by conventional systems, may require special protection in stern or keel areas. All require special protection of rudders, shafts, shaft tubes and struts. This special protection can be provided best by coal tar epoxies. It has also been used on hundreds of crafts over the entire exterior hull area where service conditions are severe.

Plates Usually Perforate From Inside

It has been shown that, where perforation of hull plate occurs by other than mechanical means, it generally occurs from corrosion and, generally, from inside to outside. This is not true of deck areas. Generally, where deck areas have to be renewed from other than mechanical damage, they have been weakened by corrosion from the topside. Because weather decks are always in view and there is always a man and a bucket of paint available, they can be touched up as often as necessary.

Other decks are less obvious, receive less attention and so are more frequently replaced. On these decks corrosion generally proceeds from outside to inside. There is a considerable amount of flexing of deck areas and are also many points of attachment of bulwarks, bitts, waterways, fittings, coamings for hatches, etc. Brittle coatings cannot absorb the flexing and thin film coatings usually fail first at points of attachment. A non-skid surface produced with the coal tar epoxy is integral with the anti-corrosive. Where color coating of the deck is desirable, as on military craft, a choice of colors is available by use of an approved catalyzed epoxy top coating.

Losses Greatest in Bilges, Tanks

In tonnage of metal lost through corrosion, bilges and tanks probably lead. The irregular surfaces and gaps make protective coating a real problem. A great deal has been done about tank coating. However, there is no unanimity of opinion concerning the problem, or its solution.

A recent method of protecting tanks involves the use of coal tar epoxy over part of the tank surface with cathodic protection of the other parts. To permit easy renewal of anodes, all are located on the walls of the tank near the tank deck. Thus they can be replaced by a man standing on the tank deck without the use of scaffolding.

The coating is used as an anode shield over all of the tank deck and up on the walls of the tank to a height of several feet above the location of the anodes. This system requires an extension above the top of the tank which permits complete flooding of all the tank surface. Experimental applications indicate that the throw of the anodes will be adequate to protect the upper, bare surfaces of the tank. While still in an experimental stage, this treatment of tank surfaces offers some promise.

Bilges Have Had Little Attention

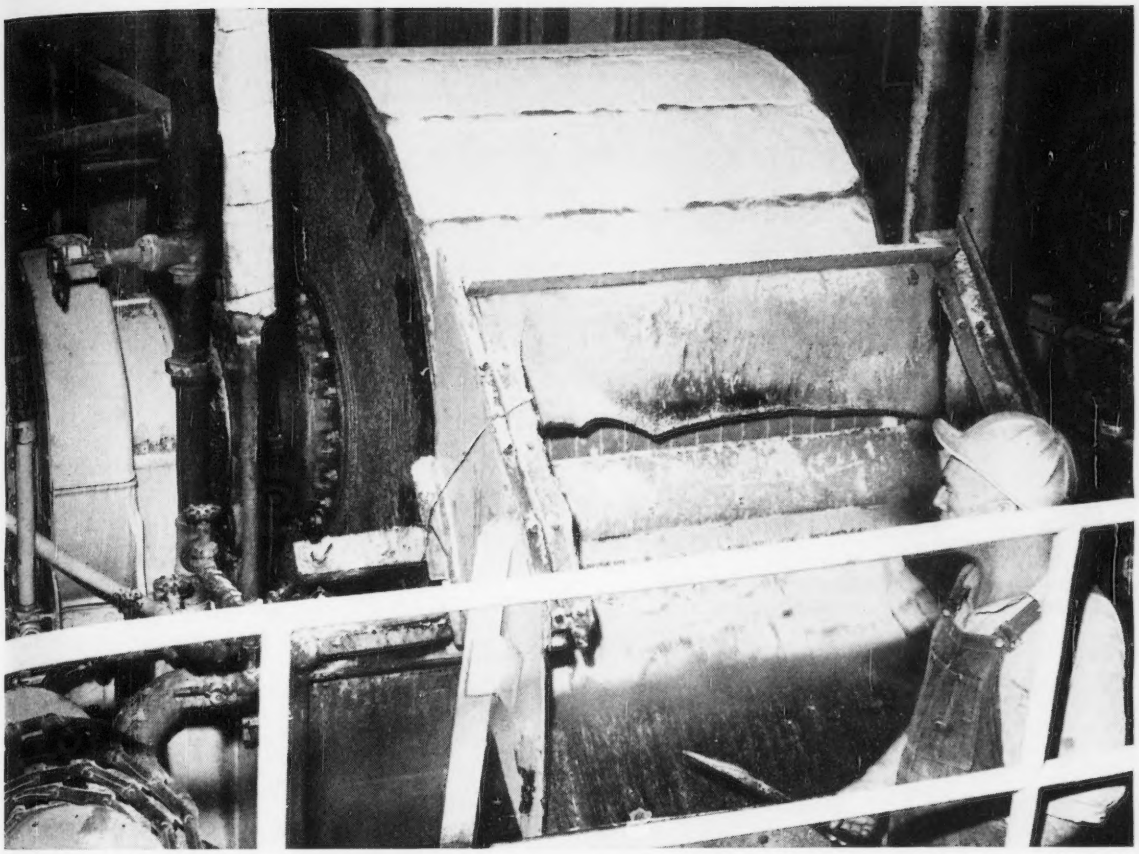
Bilges and double bottom tanks, however, have not been recognized as a critical problem so they have not received any great attention. As noted in the Part 1 of this article, owners often seem to be unaware that bilges will corrode. So, it has been difficult to get much done about them. The change to lighter scantlings has caused a number of owners to admit the problem and they are doing something effective about it.

Thin film coatings requiring five to eight coats to attain a dry film thickness of five to eight mils, can and have been used to coat bilges. However, they are not used extensively. The costly multiple coats, as well as their volumetric cost, result in a high applied cost. Also, the thin films fail to adequately protect the nooks, crannies, crevices, gaps and other irregularities found after fabrication of heavy structural components. Also, they generally are low solids systems diluted with highly volatile aromatic solvents to constitute a serious explosion and flammability hazard.

While the old conventional drying oil materials can be applied in a number of coats to a thickness better suited to the needs of this service they lack the required chemical resistance. Furthermore, they ultimately cure to a hardness such that the 8 to 10 mil film will crack

(Continued on Page 40)

Make SEA WATER
-ANYWHERE!
SEA RITE SALT
for CORROSION STUDIES
4½ oz. Sea Rite Salt crystals in one gallon tap water produces laboratory sea water quickly, inexpensively. Provides uniform, constant results based on 77 composite analysis. Immediate delivery — any quantity. Technical literature on request. Write, wire, phone now!
LAKE PRODUCTS CO., Inc.
ST. LOUIS 25, MISSOURI



Vacuum filter extracts mixed salts from a brine containing 12-15% $MgC1_2$, 7.5% $MgS0_4$, 4% NaC1, 5% KC1. Monel alloy resists all these corrosives and also overcomes the possibility of failure due to chloride ion stress-corrosion cracking. Filter is installed at Carlsbad, New Mexico plant of International Minerals and Chemical Corporation.

How Monel alloy stopped $MgCl_2$ stress-corrosion cracking of this filter

Chloride ion stress-corrosion cracking destroyed the original core of this drum filter in less than six months. During this time, general corrosion of the core contaminated the process stream with heavy metal salts.

Then, engineers of International Minerals and Chemical Corp. replaced the cracked core with one made of Monel* nickel-copper alloy. After the Monel alloy core was installed, you could scarcely believe it was the same machine. Trouble vanished overnight.

When stress-corrosion is a problem...

Monel alloy...or one of the other high nickel Huntington Alloy Products... can be depended upon to control it.

Monel alloy is free from chloride ion stress-corrosion cracking... under conditions of total immersion, intermittent wetting and drying or vapor exposure, and in the presence of residual welding or applied stresses and crevices.

Monel alloy has also demonstrated remarkable resistance to general attack by chlorides...neutral and alkaline salts, acid salts, and salt waters, including high velocity sea-water.

Easy to fabricate

Monel alloy is not an exotic metal. It's readily available. What's more, fabricators know exactly how to cast, shape, and weld it for use in pumps, piping, coils and all kinds of processing vessels.

For information on the engineering properties of Monel alloy and for advice on applying those properties to specific items of equipment, contact:

*Inco Trademark

HUNTINGTON ALLOY PRODUCTS DIVISION
The International Nickel Company, Inc.
Huntington 17 West Virginia

What every engineer should know about Chloride Ion Stress-Corrosion Cracking

Cracks . . . large, straight or branched, usually transgranular but may be intergranular.

Causes . . . It is best explained as an electro-chemical mechanism with crack initiation being related to the available oxygen, specific concentrations of the chloride ion, and the stress level.

Potential . . . Stress-corrosion cracking has been observed in engineering materials that have been cold worked, rolled, welded, periodically wetted and dried. It may occur at stresses as low as 2000 psi; water containing as low as 50 parts per million chloride and at temperatures as low as 100°C.

MONEL®

Ship Corrosion—

(Continued From Page 38)

and fail at discontinuities under strain. Their abrasion resistance is limited.

No time for Drying Oil Systems

Production schedules in construction and repair yards also have had a great deal to do with eliminating the drying oil materials, most of which require a lengthy drying period before application of additional coats. Production schedules usually do not permit holding up operations to wait for a paint to dry properly, so additional coats are applied over inadequately cured undercoats. The result a film too soft to serve the purpose for which it is intended.

When coal tar epoxies are used for this service they exhibit extraordinary adhesion to sand-blasted steel and may be applied to a minimum dry thickness of 16 mils in only two coats. Their abrasion resistance is excellent so they are often used because of this property. Being heavy bodied, they fill small voids and close small openings which would not be closed by lower viscosity materials. Also, they are resistant to sea water, petroleum products and many chemical solutions containing considerable percentages of acids, alkalies and salts.

As pointed out in the first paper, a number of other internal areas in a ship need new methods and new materials to reduce maintenance costs caused by corrosion. One of the more important of these materials is a hydrocarbon filled fire retardant mastic thermal insulating material which gives a good vaporseal and is non-corrosive. The vapor pressure difference between the occupied space in a ship and the inside face of the hull plate, especially in winter months, is substantial. It is usually sufficient to drive atmospheric moisture against the cooler surfaces, where it condenses. Some cases are on record where the absorbent type insulation has been so saturated with condensation from such action as to fall of its own weight.

One of the substantial, though incidental gains from the use of adequately anti-corrosive materials is improved appearance.

Some of the things necessary include the following:

1. Owners and operators must acknowledge the existence of the corrosion problem which grows more severe with the trend to lighter scantling construction.
2. A good job while the ship is on the ways may cost a fraction of the cost of doing the job over and over again in drydock.
3. A "good job" results only from tight specifications requiring effective methods and the best materials under continuing, disciplined supervision and rigid inspection.
4. It must be recognized that part of the ship's environment, the sea, is an electrolyte. If there are dissimilar metals in the structure, there will be corrosion.
5. The best possible protective coating, applied in the best possible ways, with adequate cathodic protection and best protective practices, can save many dollars.
6. Many new "specialized" materials of construction are needed to meet today's design demands, such as:

a. A light weight, resilient, flexible, vapor-sealing thermal insulation material for interior decks that can be overlayed with tile as flooring.

b. A light weight, high strength, sound dampening material which is a complete vapor-seal and independent of adhesives.

c. A metal-filled putty for use as a fairing compound which retains resilience.

d. Materials for special uses which have sufficient strength, abrasion resistance and adequate resilience as well as non-skid properties for deck areas subjected to extremely severe service. These materials must be corrosion resistant.

APEX

Magnesium Anodes

THE FINAL LINK IN CORROSION CONTROL

Cathodic protection is essential to *maximum* protection against corrosion of underground and underwater pipelines and other metal structures—the indispensable link in *any* chain of protective methods.

APEX anodes are available in 3 lb., 5 lb., 10 lb., 17 lb., 32 lb. and 50 lb. sizes. Prompt service on bare anode with or without wire, or complete packaged anode with wire and back-fill ready for installation.

Send without obligation for our folders detailing the composition, installation, function and dollar-saving performance of Apex magnesium anodes. Our engineers are available for qualified technical consultation.

APEX SMELTING COMPANY

2537 West Taylor Street, Chicago 12, Illinois

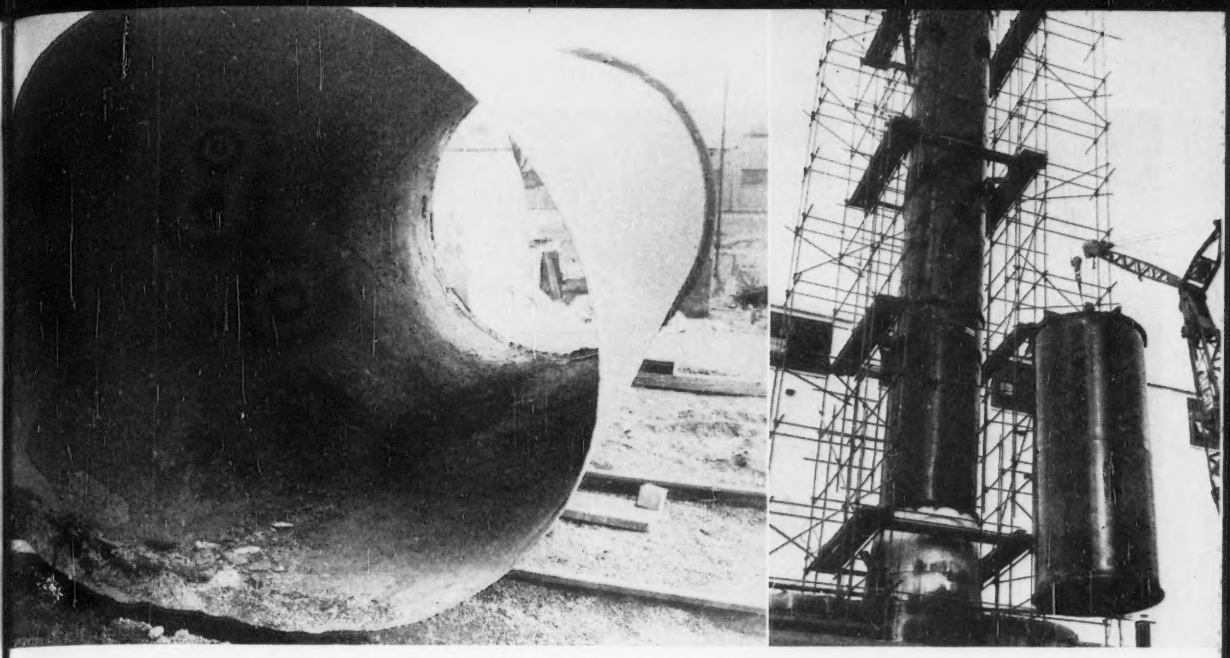
Cleveland 5, Ohio • Long Beach 10, California

1960 Corrosion Show Color Slide-Talk

A show consisting of 108 color slides has been prepared showing some of the exhibits at the March 15-17 Dallas exhibition. This 1960 Corrosion Show color slide presentation will be accompanied by a commentary describing the exhibits and many of the items displayed.

NACE Section program chairmen who are interested in using this in one of their programs may make bookings by writing to G. A. Rolak, 1061 M & M Bldg., Houston 2 Texas.

The show gives members who were unable to attend the conference an opportunity to see some of the exhibits at what many have said was the best Corrosion Show held so far.



CORROSION FAILURE of the steel smokestack above occurred after only seven years. Glass coated stacks are expected to triple that service life.

Glass Coatings Solve Smokestack Corrosion

Steel Stack Fails After Seven Years' Boiler House Service

Most unlined carbon steel smokestack failures are caused by corrosion inside the stack. Moisture in flue gases, when cooled to about 300 F or less, condenses against the stack internal surfaces. Because most fuels contain sulfur, sulfurous gases formed in combustion mix with the condensed moisture to form acids which severely attack steel, painted steel and other types of stack linings. The attack is more severe in the upper portions of the stack where low temperatures and condensation are most common.

An example of stack failure is shown in the photograph above. This steel stack section was used in ordinary boiler house bituminous coal service at the Oscar Mayer Company, Madison, Wis. The ⅜-inch steel stack was corroded beyond use after a service life of only seven years.

An economizer was installed to recirculate and extract heat from flue gases. Although this increased the boiler's efficiency, it also intensified corrosion in the stack by lowering the flue gas temperatures, thus giving more condensation.

Glass Coated Stacks

One solution to this stack failure is use of stacks which are protected inside and out with special acid resistant glass coatings, such as the stacks shown in the photograph at right above, manufactured by the Process Equipment Division of the A. O. Smith Corporation, Milwaukee, Wis.

More than 15 ingredients are blended and melted at 2400 F to make the glass. The molten mixture is poured into running cold water which solidifies and shatters the glass into tiny particles called frit. This is finely ground and mixed with clay and water, resulting in a mixture called slip. After the stack surfaces are sandblasted to remove all foreign matter and to roughen the steel surface for a good bond, the slip is sprayed on external and internal surfaces of the stack and dried at controlled temperatures. The coated stack is then fired at 1650 F in a furnace and given a second coat.

The external glass coating can have custom colors added if desired.

Service Life Expected

Glass coated stacks are expected to give service life three to five times that of plain steel stacks in similar service. Designed to resist hydrochloric, sulfuric, nitric and phosphoric acids, glass coated stacks have been tested to withstand acid attack at operating temperatures to 750 F for maximum continuous duty.

These stacks are designed to eliminate interior maintenance. Brick or concrete lined stacks often require frequent interior maintenance to prevent flue gases from seeping through cracks to begin the corrosion process hidden behind the lining material.

Sea Horse Institute Studies New Problems Needing Research

Two hundred corrosion specialists discussed 84 questions related to marine corrosion at the annual Sea Horse Institute held May 30 to June 3 at Kure Beach, N. C.

Purpose of this informal conference was to marshall existing knowledge which can be applied to specific marine corrosion problems to indicate areas where investigation is needed and to outline tests which will give definite answers.

Attendants observed such tests in progress at International Nickel Company's test stations at Kure Beach and Harbor Island.

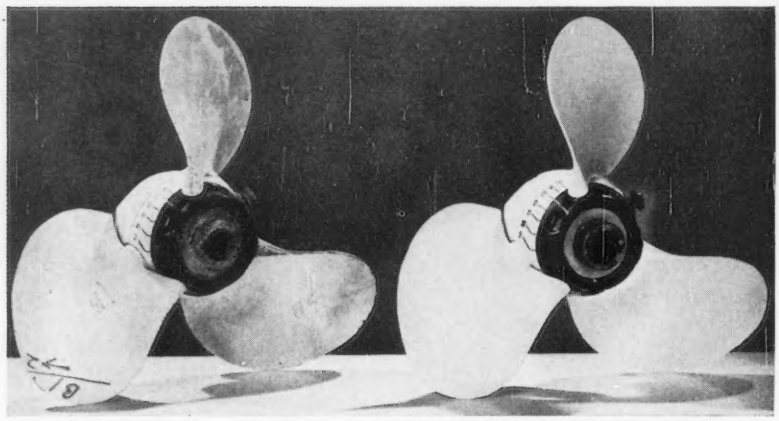
One group of tests sponsored by the U. S. Navy is aimed at selecting proper materials for hydrofoils which operate at 90 mph or more in sea water. A test was devised to determine resistance of metals to sea water at speeds to 130 mph. Thus, as new services are demanded of metals, new tests must be devised to aid in the selection of the most useful and most economical material.

The program covered the basic properties of metals including effects of specific alloying elements and specific corrosion effects such as cavitation, stress, velocity, temperature, etc., as they relate to marine atmosphere and sea water.

Special problems dealing with wood and steel piling, ships, heat exchangers and salt water conversion to fresh water also were discussed. A large portion of the program pertained to application of cathodic protection and protective coatings.

Program leaders were NACE members F. L. LaQue, T. P. May and David B. Anderson. Questions which had been submitted by persons attending previous sessions were arranged in logical order by T. P. May for discussion at the meetings.

RECORD and REPORT



ALUMINUM VARIABLE PITCH PROPELLER for outboard motors on the left withstood salt water testing for over five months. The entire prop was immersed in synthetic sea water for 10 minutes, then removed to dry for 50 minutes. The test was continued 24 hours a day for over five months. Comparison of the tested propeller with a new one on the right shows the tested prop was in good condition and was easily switched to each of seven pitchs despite a salt crust on assembly.

Aluminum Propeller Resists Five-Month Salt Water Tests

An aluminum variable pitch propeller for outboard motors of 25 to 45 horsepower has withstood a gruelling five-month salt water test. Corrosion was insignificant after 4650 ten-minute immersions in a salt tank.

The continuing salt water testing of the assembled propeller is conducted under controlled conditions to simulate a three-year average use test. The entire prop assembly is immersed in synthetic sea water for 10 minutes, then removed to dry for 50 minutes. Temperatures are between 70 and 80 F. The test has been going on for 24 hours each day for over five months.

Close examination of the prop after a five month period in the test showed only slight flaking of the acrylic finish on the blades without any damage to the aluminum components. Even though caked with dried salt crystals, the prop's pitch selector ring turned properly and allowed setting of the seven pitches.

The main housing and replaceable blades are die cast of 218 aluminum alloy fabricated by Aluminum Company of America.

The tests are being conducted by Alcoa's Research Laboratories Cleveland division in cooperation with Lesnor-Maehr Marine Co., Inc., 118 Cherry Lane, Floral Park, Long Island, N. Y., manufacturers of the propeller.

The tests are scheduled to continue in an effort by both companies to improve the durability of the assembly.

Agglomeration Symposium To Be Held April 12-14

The first International Symposium on Agglomeration held in America is scheduled for April 12-14, 1961, at the Sheraton Hotel, Philadelphia, Pa. Sponsored by AIME, the symposium is expected to draw hundreds of engineers, scientists, industrial personnel and educators from many countries.

Theme of the symposium will be the basic mechanisms common to agglomeration processes in general. Specifically, the symposium will deal with processes of sintering, pelletizing, nodulizing, briquetting, powder metallurgy, ceramic bonding and related processes.

Belgian Corrosion Course

A course will begin in October in Belgium on the use of electrochemical methods at high temperatures, under the sponsorship of Cebelcor (Belgium Center of Corrosion Studies). Studies will be made on the mechanism of corrosion of materials at high temperature, especially of refractory materials and the improvements and developments of current practices and theories of electrochemical and thermodynamic behavior in aggressive cases.

•

A Short Course on Process Industry Corrosion, sponsored by NACE Technical Committee T-5 and Ohio State University, will be held Sept. 12-16 at Columbus.

•

News deadline for CORROSION is the 10th of each month.

HARD RUBBER LINING is being applied and finished for this six-ton absorber dip leg which will serve as an integral part of a dye stuff process. The lining is designed for chemical resistance at Allied Chemical and Dye Corporation's National Aniline Division Plant at Martinsville, W. Va.

New European Method Developed for Joining Vinyl Water Mains

A new European method of joining vinyl pipe uses a conventional bell and spigot type slip joint coupled with a butadiene-acrylo-nitrile rubber O-ring. In Denmark, the method has been incorporated into official standards for water mains.

One end of each pipe length is heated and belled out on a mandrel so that the inside diameter exceeds the outside diameter of the plain pipe end. An O-ring made of nitrile rubber is slipped over the plain pipe end which is then pushed into the bell end of the next section of pipe. The O-ring then rolls and places itself into position in the middle of the bell.

A portable oven, using infra-red lamps or bottled gas, is placed around the bell which is heated for four to eight minutes to complete the joint. When heat is applied, the bell tends to return to its original shape and dimensions, thus squeezing tightly around the plain pipe end and the O-ring.

Conventional expansion joints are not needed because the joint can move sufficiently to take up any expansion and contraction caused by temperature changes.

The nitrile rubber used for the O-rings is Hycar, a product of B. F. Goodrich Chemical Company, 3135 Euclid Ave., Cleveland 14, Ohio.

Research Contract Awarded For Graphite Missile Parts

A three-year research and development contract on graphite for missile and vehicle components has been awarded by the U. S. Air Force to National Carbon Company, division of Union Carbide Corporation.

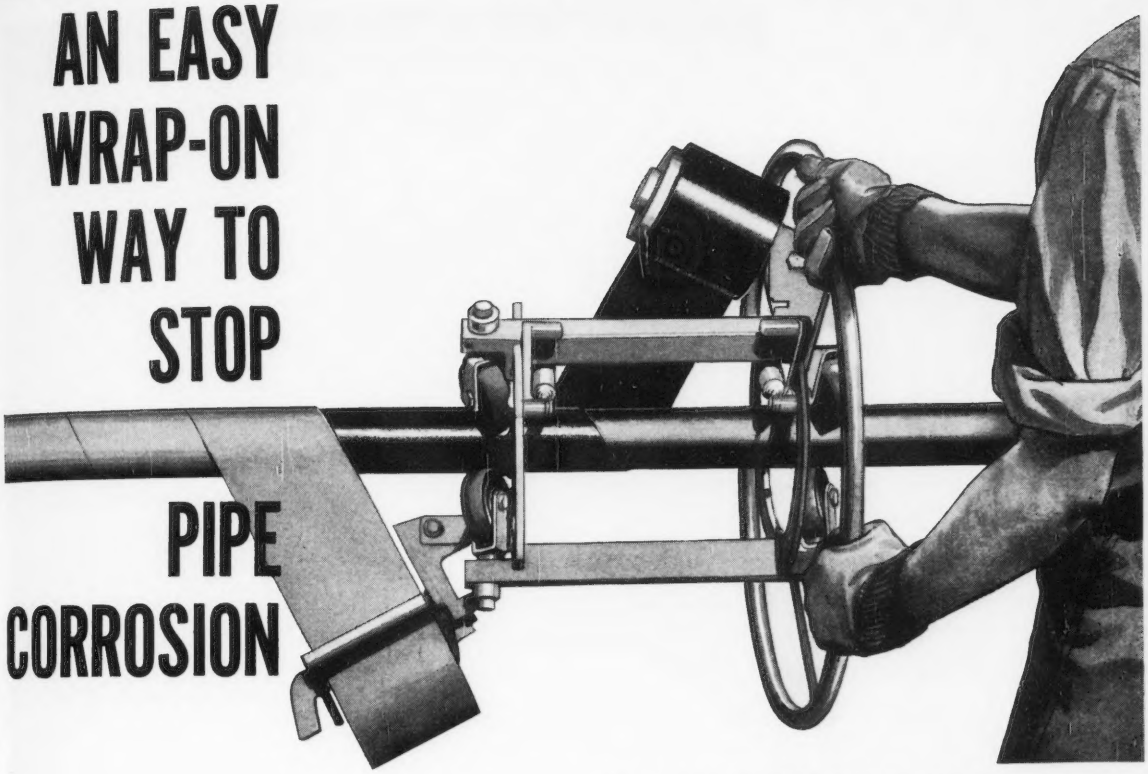
Objectives of the 12 million dollar contract are to explore raw materials and processing techniques that will (1) significantly reduce variation in mechanical and physical properties to about one-third the present variation found in the best grades of graphite available today, (2) reduce total manufacturing time for graphite from many weeks to several days, (3) achieve these objectives for pieces larger than three feet in diameter by six feet in length and (4) develop a processing facility to produce such graphites in quantity sufficient for proper evaluation under full scale conditions.

High Temperature Forming Technique Used for Metals

Shaping rugged metals for use in supersonic aircraft and missiles is expected to be quicker and less expensive through a new high temperature forming technique developed by Republic Aviation Corporation.

A small die press weighing less than a ton has been built that can do the work of a 750-ton hydraulic press, according to Republic Aviation. The process involves precision casting of dies from a special alloy of beryllium and copper. This alloy is used for a hot tooling material that will retain its high strength and mechanical properties at extremely high temperatures.

AN EASY WRAP-ON WAY TO STOP PIPE CORROSION



The new CORR-PREV Pipe Coating Team comes in easy to handle tape form. It goes on pipe faster and lasts longer than corrosion-proof paints. It's cleaner and simpler to apply, too, than hot tar coats. And most important, this new CORR-PREV Team offers all the cost-cutting, pipe-saving advantages of *polyethylene* tape.

With CHASEWRAP Abrasion-Resistant Overwrap and Chasekote polyethylene tape, you get the easiest and best pipe protection at *lowest applied cost!* There's no heating, drying, clean-up or shut-down time. Each roll is factory-uniform in thickness and quality. And all coating materials — including rental of high-speed applicators — are available from one reliable source. Want samples? Specs? Prices? Write **CHASE & SONS, INC., 26 Spruce St., North Quincy, Mass.**

Chasekote*

Pressure-Sensitive Polyethylene Tape has an extra-heavy adhesive mass that clings to clean pipe on contact . . . makes a perfect, permanent bond that rustproofs, waterproofs and insulates pipe against all types of corrosion.

Chasewrap*

Protective Overwrap is a tough, wrinkle-free outerwrap that shields against abrasion, wear, and physical damage to the tape. Wraps simultaneously with the tape. Superior to rag and felt wraps, yet far lower in cost.

**Trade name of Chase & Sons, Inc., long-famous for protective and insulating tapes for electrical wire and cable*

Refineries & Gathering Systems

Public Building Lines

Oil & Gas Transmission Lines

(CORR-PREV) DIVISION

Highway and Airport Conduit & Pipe

Utility Distribution Systems

Chemical & Industrial Plant Piping

FOR YOUR ELECTRICAL INSULATION PROBLEMS SPECIFY CHASE FRICTION, PLASTIC, RUBBER, NEOPRENE AND BUTYL TAPES

TYGON®

Low Cost, Long-lasting Protection Against Corrosive Attack

There's only one sensible way to measure cost when you buy paint to protect processing equipment, and that's *cost per year per square foot of protection.* A few pennies saved in cost per gallon can mean dollars lost if the paint fails on the tank.

That's why you'll find many chemical plants with low cost maintenance records use Tygon Coatings almost exclusively to provide maximum protection at minimum cost.

412F-1

Write for Bulletin 760

U. S. STONEWARE

AKRON 9, OHIO

NEW YORK • CHICAGO • HOUSTON • LOS ANGELES

Corrosion Minimized By Silverplating in Giant Autoclave

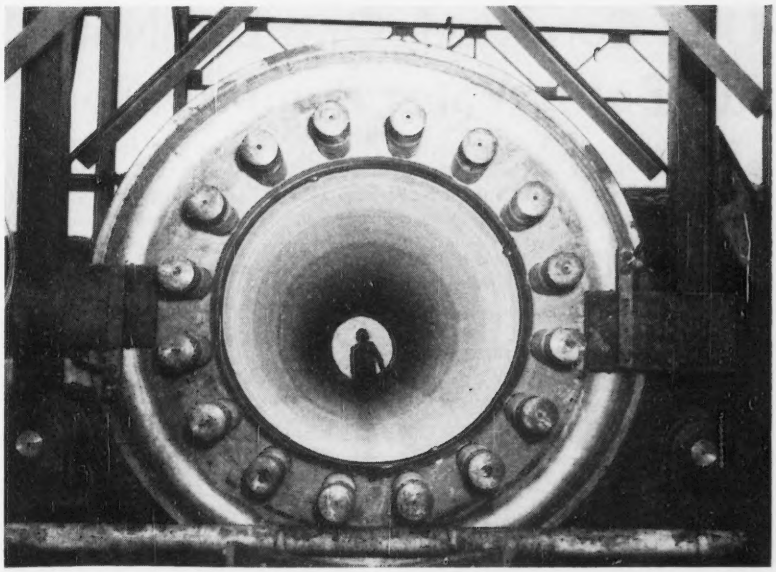
Forty-five thousand dollars may seem an unreasonable amount of money to spend on one piece of equipment just to prevent product contamination and to minimize corrosion. But this amount of money, at current silver prices, was represented by the 50,000 ounces of silver which were plated on the interior of an autoclave used in urea manufacturer.

The giant sterilizer is 44 feet long with an outer diameter of 54 inches. It weighs 110 tons and is fitted with two end plugs, each weighing 2½ tons.

The railroad flatcar used to transport the autoclave was switched to a spur track and covered with a large tent because the car and autoclave were too large to be taken into the Oneida silversmith plant.

Before plating could begin, the Oneida engineers had to install bearings on the floor of the flatcar so that the autoclave could be revolved continuously during the plating operation. This revolving mechanism had to be so perfect that it could withstand the 60 hours of continuous operation necessary to silverplate the autoclave interior.

The autoclave is used by Cyanamid of Canada Limited at Hamilton, Ontario. Oneida silversmiths, makers of tableware, performed the plating operations.



SILVERPLATED AUTOCLAVE prevents product contamination and minimizes corrosion of the unit used in the manufacture of urea. Left on its railroad flatcar, the autoclave was resolved during the plating operation by the rollers seen on each side of the unit. About 50,000 ounces of silver were required for the plating.

Submarine Speeds May Be Increased by New Paint

Rubber-like paint which cuts water turbulence around a body moving through water may enable ordinary submarines to slip through water at speeds near 70 mph, according to a story in the February issue of "Industrial Research Newsletter," published by Armour Research Foundation.

Developed by Max O. Kramer of Coleman-Kramer, Inc., the paint consists of thin layer of rubber supported on boat's surface by multitude of tiny rubber pillars. With predicted perfection of the paint plus coming engine improvements, future passenger and cargo submarines may be able to travel at speeds approaching 207 mph.

Auto Ruling Suggested for State Air Pollution Law

No motor vehicle manufactured after January 1, 1961, should be permitted to be sold within California unless it is equipped with an exhaust control device approved by the State air pollution agency as meeting standards fixed by that agency.

This ruling has been suggested for state legislation by the Los Angeles County Air Pollution Control District as a possible means of helping solve the area's smog problem.

ASTM Corrosion Committee

ASTM Committee A-5 on Corrosion of Iron and Steel has completed work on a new specification covering zinc coated iron or steel sheets for culverts and underdrains. Work is continuing on specifications for aluminum coated iron and steel sheets.

Auto Exhaust Nitrogen Reduced by New System

Oxides of nitrogen in auto exhaust can be reduced 80 to 90 percent by introducing a small amount of cooled exhaust gas into the intake system of the engine, according to a recent report of the Air Pollution Control District to its Board of Supervisors in the County of Los Angeles, Cal.

This discovery makes available a principle of control for all major contaminants in auto exhaust. The others (hydrocarbons and carbon monoxide) can be controlled by afterburners.

Talk Given on Cathodic Protection of Pipelines

Cathodic protection on underground pipelines was the subject of a talk by C. A. Erickson, NACE member who is chief corrosion engineer with Peoples Natural Gas Company, given at a March 11 meeting in Pittsburgh, Pa.

A total of 65 attended the meeting, representing pipeline contractors working with gas companies, local pipeline corrosion control product suppliers and gas company personnel. The afternoon and dinner meeting was sponsored by the Equitable Gas Company, New York State Natural Gas Company and Peoples Natural Gas Company.

The American plastic industry tripled its production during the 1950's from 1.6 billion pounds in 1950 to 5.4 billion pounds in 1959.

FOCUS ON CATHODIC PROTECTION

Six articles on various aspects of cathodic protection operation and application will be published in August Technical Topics Section. This focus on cathodic protection is designed to concentrate CORROSION's readers' attention on the subject and emphasize the outstanding performance of the magazine in covering the technical and management aspects of this subject.

The articles to be published are as follows:

Value of Corrosion Protection on Pipe Line Systems—Management's Viewpoint by Harry K. Phipps, Central Pipe Lines Div., Mobil Oil Co., Wichita, Kan.

Suggested Methods and Practices of Cathodic Protection Coordination by David T. Jones, Pacific Telephone and Telegraph Co., Los Angeles.

Ten Years of Cathodic Protection for Large Water Storage Tanks by H. M. Patton, Brown Shoe Co., St. Louis.

Engineering and Design Problems Affecting Cathodic Protection of Lacq Field Well Casings by M. Estavoyer, Societe Nationale des Petroles D'Aquitaine, Paris, France.

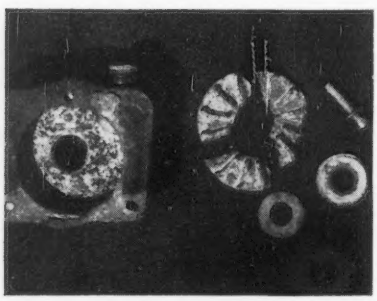
Pipe-Type Cables Protected by Shunt Resistor System by H. H. deLaneux and H. A. Medlock, Pacific Gas & Electric Co., Emeryville, Cal.

Novel Distributed Cathode Systems on Telephone Cables by Douglas T. Rosselle, Southern Bell Telephone and Telegraph Co., Atlanta, Ga.

One Corroded, One Did Not— But Both Water Pumps Failed

This is the story of two pumps. One corroded, one did not, but both failed. The pumps were installed in a heat exchanger unit of a home air conditioning system to spray cooling water over a finned tube unit removing heat from the Freon compressor cycle. The original pump installation lasted about two and one-half years. The replacement pump started leaking after about six months' service.

Because the compressor units and other moving parts of this system are designed for about 5 years' service the short life of the pumps creates unnecessary expense and operating difficulties.



This pump lasted 2½ years. Impeller blades in the rotor were badly corroded, and the screw fitting at top was damaged. The rotor blade had to be destroyed in order to remove it from the steel motor spindle.

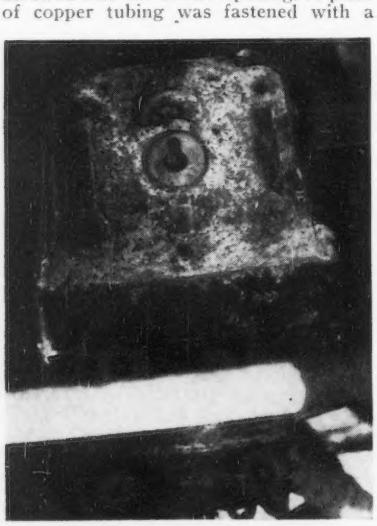
Shown above is the original pump. The case is metal (probably zinc). There is a hard rubber (?) insert in the case wherein the pump impeller operates. Parts of the cast zinc pump impeller and two washers are shown. The efficiency of this pump was so reduced by corrosion after two years of service it had to be removed. It was broken in removal.

The zinc impeller was fastened onto a steel motor spindle. A brass nipple screwed into the center opening. A piece of copper tubing was fastened with a brass compression fitting into the outlet projection (upper right). This projection was corroded away and would not hold the fitting.

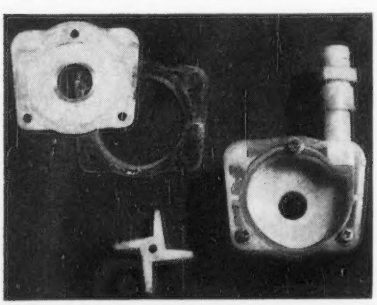
The substitute pump (below) is made of nylon. The impeller is made of nylon also. A nylon plate fits against the circular sealing surface (blackened to show irregularity of seal). Behind the nylon plate is a non-corroding metal plate (stainless steel?) which fits against the steel case of the motor.

Only three bolts are provided to keep the compression seal tight. After about 6 months' use the pressure of the bolts had so distorted the nylon that a severe leak developed around the pressure seal.

The motor (bottom left) is a totally-enclosed steel cased type. It is not fastened to the unit, but hangs from the pump, which is fastened to the unit by the water piping fittings only.



This totally enclosed, steel cased motor dangles from the pump and is not fastened to the heat exchanger case.



This pump leaked after six months. Only three bolts were used to maintain a pressure seal. Bearing surface has been graphited to show irregularities resulting from distortion under stress from bolts.

Ceramic Printed Circuits Can Be Mass Produced

Ceramic printed circuits can be mass produced in sizes to 18 square inches for high temperature applications in missiles and aircraft. The high alumina bodies and moly-manganese circuits screened on can be subjected to temperatures to 1800 F without failure and will withstand equally exacting humidity and corrosive environments, according to Harvey Pensack, president of Mitronics, Inc., 1290 Central Ave., Hillside, N. J.

FOCUS ON CATHODIC PROTECTION

Six articles on cathodic protection will be featured in the August Technical Topics Section. Subjects to be included are telephone cables, oil field equipment, pipelines and inter-company cooperation.

New Plants

Du Verre, Inc., of Arcade, N. Y., fabricators of corrosion resistant resin bonded fiberglass equipment for the process industries, has doubled its production area with a new steel frame building.

•

Sinclair-Koppers Chemical Company has awarded the contract for design, engineering and construction of a new styrene monomer plant to be built in Houston, Texas. The new plant will have a design capacity of 70 million pounds per year and will be the first licensed by Cosden Petroleum Corporation under its styrene-from-gasoline process.

•

Flintkote Company, 30 Rockefeller Plaza, New York 20, N. Y., will build a new plant in Vancouver, British Columbia, Canada, to manufacture Flintkote's resin-asbestos and vinyl floor tile.

•

Pittsburgh Chemical Company has begun production at its new sulfuric acid plant at Neville Island on the Ohio River. The new facilities will boost the company's capacity by 70 percent.

•

A plant to manufacture 105 percent phosphoric acid is being built by **Monsanto Chemical Company's** Inorganic Chemicals Division at Addyston, Ohio, near Cincinnati. A natural desiccant, the product is 40 percent more concentrated than normal 75 percent acid and offers several advantages to various industrial and chemical processing industries.

Hertz Foundation Offers Engineering Scholarships

The Fannie and John Hertz Engineering Scholarship Foundation makes available financial aid in schooling and training to needy engineering students whose talents will be of value to the U. S. in times of emergency.

Graduating high school seniors can apply directly or through their high school, irrespective of race, religion or sex, if they intend to pursue engineering studies but lack sufficient funds, if they are in the upper 25 percent of their class and if they have a strong science and mathematics curriculum background. In some cases college undergraduates also are considered. Awards are for one year, renewable annually.

Additional information can be obtained by writing Stevens, Manning & Associates, 6351 Wilshire Blvd., Los Angeles 48, Cal.

Welding Galvanized Steel

Problems of the automotive industry in welding galvanized steel are being studied in a new research project conducted by the Budd Company of Philadelphia, Pa., under the auspices of the American Zinc Institute.

The project is aimed at development of an economical process for production line welding of galvanized steel—of major importance to the automotive industry now that unitized bodies are being used by the major auto manufacturers.

Beat Corrosion *with the different polyester...*

ATLAC® 382

Lightweight, sturdy, reinforced plastic equipment —made with ATLAC 382 bis-phenol polyester resin—may offer an efficient, economical solution to your equipment corrosion problems. This unusual resin has maintenance applications, too: in glass reinforced tank linings and in "putty" materials for repairing cracks and holes in steel ducts and concrete floors.

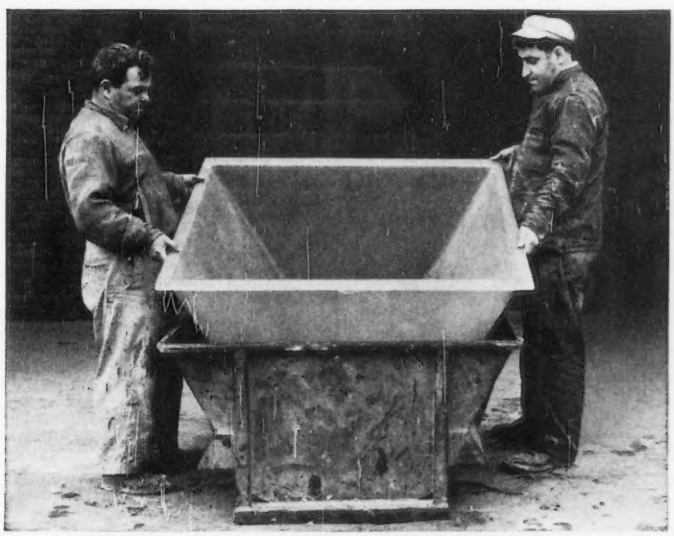
ATLAC 382 is a special, bis-phenol polyester which almost universally retains a higher percent of original strength under corrosive conditions than general purpose polyester and isophthalic resins. See for yourself—write for our new comparative study* on the effects of corrosive chemicals on various resins.

*Presented before the Society of the Plastics Industry, Feb., 1960

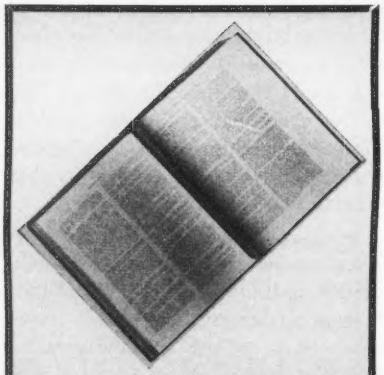
Tub Liner Beats Corrosion

The Carl N. Beetle Plastics Corporation[1] uses ATLAC 382 to fabricate corrosion resistant, seamless liners for steel tubs used to handle acids. Bonate® liners, made with ATLAC 382, extend the service life of the tubs several times beyond that which could be expected from steel alone, without a sign of deterioration by chemical attack. They're strong, lightweight, easily cleaned; surface stays free of pitting and contamination. (This application is just one of many in which the corrosion resistance of ATLAC 382 is effectively combined with the strength and economy of steel.)

[1]Subsidiary of Crompton & Knowles Corporation



CHEMICALS DIVISION
ATLAS POWDER COMPANY
WILMINGTON 99, DELAWARE
In Canada: Atlas Powder Company, Canada, Ltd.
Brantford, Ontario, Canada



Your key to more than 4287 technical articles and books on corrosion control

●

1954-1955

BIBLIOGRAPHIC SURVEY of CORROSION

NACE Members . $15.00

Non-Members . . $20.00

Topically indexed and cross-indexed according to the NACE Abstract Filing System. Alphabetical author index. Alphabetical subject index. 468 pages 8½ x 11 inches, hard cloth binding.

1952-53 volume, containing 3300 abstracts, NACE members.....$10 (Non-members $12.50)

1950-51 volume, containing 4454 abstracts, NACE members.....$10 (Non-members $12.50)

1948-1949 volume, containing 3512 abstracts, NACE members.....$10 (Non-members $12.50)

1946-1947 volume, containing 3362 abstracts, NACE members.....$ 7 (Non-members $9)

1945 volume, containing 1086 abstracts, NACE members.....$ 4 (Non-members $5)

Buy More Than One Volume and Save 10%

● Foreign remittances should be by international postal or express money order or bank draft negotiable in the U. S. for an equivalent amount of U. S. funds.

● In addition to the prices shown there is a charge of $.65 per package for sending volumes by registered book post to addresses outside the United States, Canada and Mexico.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas

Neoprene Cement Controls Cracking From Enzymes

Erosion and cracking of concrete floors in a food processing plant has been controlled by use of a special flooring of neoprene cement.

For years, concrete floors in the plant had been eroded and cracked by enzymes and sugar solutions occurring in the conversion of cornstarch to sugar. Despite all precautions, leakage, spillage and air-borne particles brought the damaging enzymes into contact with the floor. Pits and cracks developed making sanitation difficult, increasing maintenance costs and creating safety hazards.

A Chicago flooring contractor recommended a special neoprene cement called Dex-O-Tex Neotex, developed for outside decks on ocean liners. Because its basic ingredient is neoprene, which has resistance to aging, wear, chemicals, oils and moisture, the contractor believed the cement would solve the food processing plant problem.

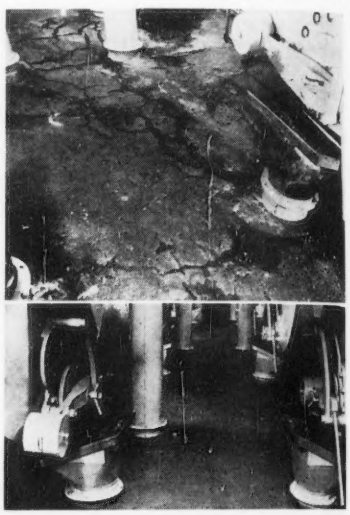
A test installation was made in 1955 in one part of the plant's corn grinding section. The flooring there was in an advanced state of deterioration with cracks, voids and crumbling areas.

First, pools of sugar solution were cleaned off. Flooring areas were scrubbed with chemical solutions. Loosened concrete was chipped down to a firm surface. Cracks and voids were filled with a special underlayment. Then a quarter-inch layer of Dex-O-Tex Neotex was applied by trowel.

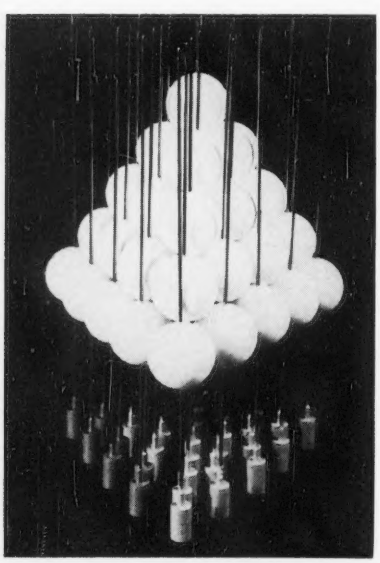
After two years' service, the new flooring was unaffected by sugar solutions. It can be readily cleaned simply by washing down with a hose. The neoprene cement gave a non-slip surface, thus contributing to in-plant safety.

After the test showed satisfactory cement performance, over 100,000 square feet of flooring were covered with the neoprene cement.

Dex-O-Tex Neotex cement was developed by Crossfield Products Corp., 140 Valley Road, Roselle Park, N. J. Neoprene is manufactured by Du Pont's Elastomer Chemicals Department as a basic material for industry.



CEMENT FLOORING, eroded and cracked severely by enzymes and sugar solutions in a food processing plant as shown in the top photograph, was repaired by using a special neoprene cement. The repaired floor (bottom photograph) has given over two years' service without cracks or failures.



CRYSTAL LATTICE MODEL to demonstrate crystal structure of matter in chemistry, solid state physics and mineralogy can be made from a construction kit of balls about the size of ping-pong balls and needles.

Kits Are Available To Build Crystal Lattice Models

Crystal lattice model construction kits are available for building three-dimensional demonstrations of crystal structure of matter in chemistry, solid state physics and mineralogy.

The kit includes red, green and white spheres the size of ping-pong balls with punched holes for mounting on steel needles which have magnetic bases, rubber washers to position the balls on the needles and a steel base plate. The magnetic needle bases permit inclining the base plate to show oblique lattice planes from every side.

Different lattice models can be built to show the systematic arrangement of crystals and crystallographic properties such as periodicity and symmetry. A small model can be enlarged periodically in the direction of the three coordinates to show origin and growth of crystals. Spheres can be packed closely as shown in the accompanying photograph to demonstrate how space is filled.

Additional information can be obtained by writing Arthur S. LaPine and Company, 6001 South Knox Ave., Chicago 29, Ill.

●

By 1975, the average after-tax income of USA families will be above $7000 a year—about $1500 above the present figure.

Skilled Tube-Kote inspectors approve coating quality for each length of pipe prior to shipment.

TUBE-KOTE'S AUTOMATIC WET SPONGE HOLIDAY DETECTOR

Checks Coating Superiority

You can specify Tube-Kote coatings with the assurance that every length of tubing or drill pipe will be full length inspected for coating holidays or defects. Tube-Kote's exclusive automatic inspection unit is far more accurate than previous methods. First, power supply is constant. Second, movement of the detector lance is uniform, and third, the probe sponge maintains uniform wetness by a constant feed of the electrolyte. That's why Tube-Kote can inspect the coating on each length faster and more accurately. It's another reason Tube-Kote continues to be the industry's leader. Next time specify Tube-Kote!

Our 21st Year . . . the Industry Pioneer

TUBE-KOTE®

INCORPORATED

TUBE-KOTE®

Service Mark Reg. U. S. Pat. Off.

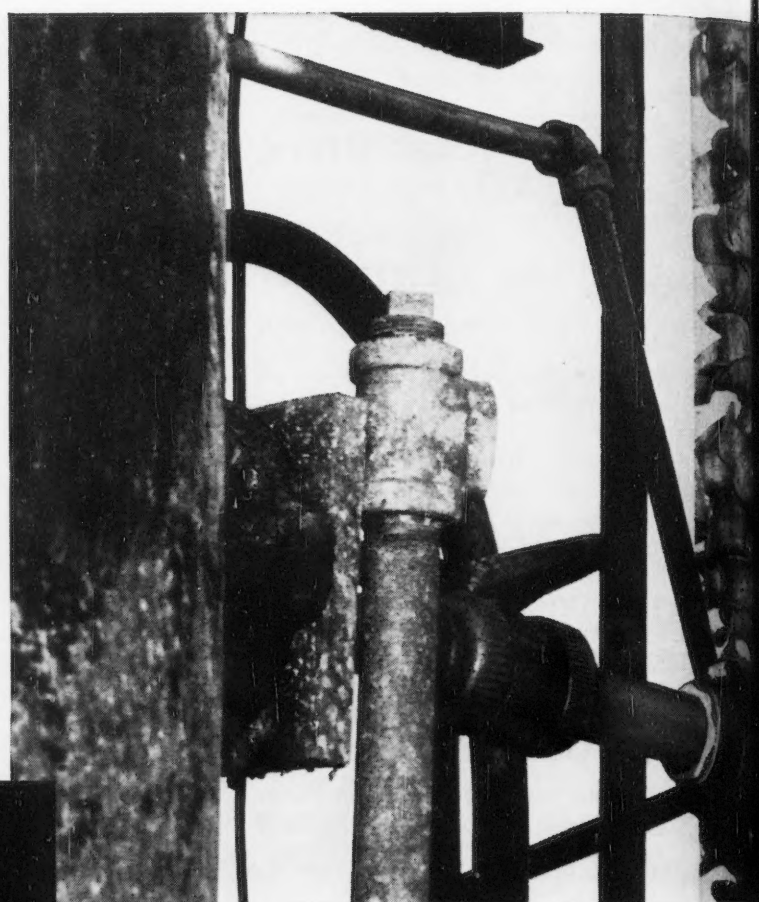
P. O. Box 20037
Houston 25, Texas

Branch Plants:
Harvey, Louisiana
Midland, Texas
Edmonton, Alberta, Canada

WHICH PENTON* PIPE IS

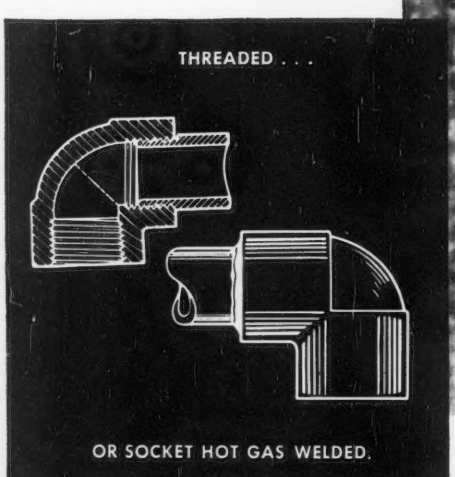
SOLID PENTON PIPE:

A rigid, uniform pipe produced by extrusion, and available in sizes from ½″ to 2″ in either Schedule 40 or Schedule 80, in lengths up to 20 feet. Use in conjunction with injection molded, solid Penton fittings with socket or threaded connections (see diagram below). Provides both interior and exterior high temperature corrosion control. Today's most versatile, all-plastic pipe.



This 1″ Penton pipe at Halby Chemical Company, Wilmington, Delaware, carries thyoglycolic acid and ether, has withstood steam-cleaning and outdoor exposure for more than nine months of service. The plastic pipe previously in use failed quickly from steam-cleaning and summer heat.

Penton pipe and solid Penton fittings by Tube Turns, Louisville, Kentucky.



COMPLETE CORROSION CONTROL

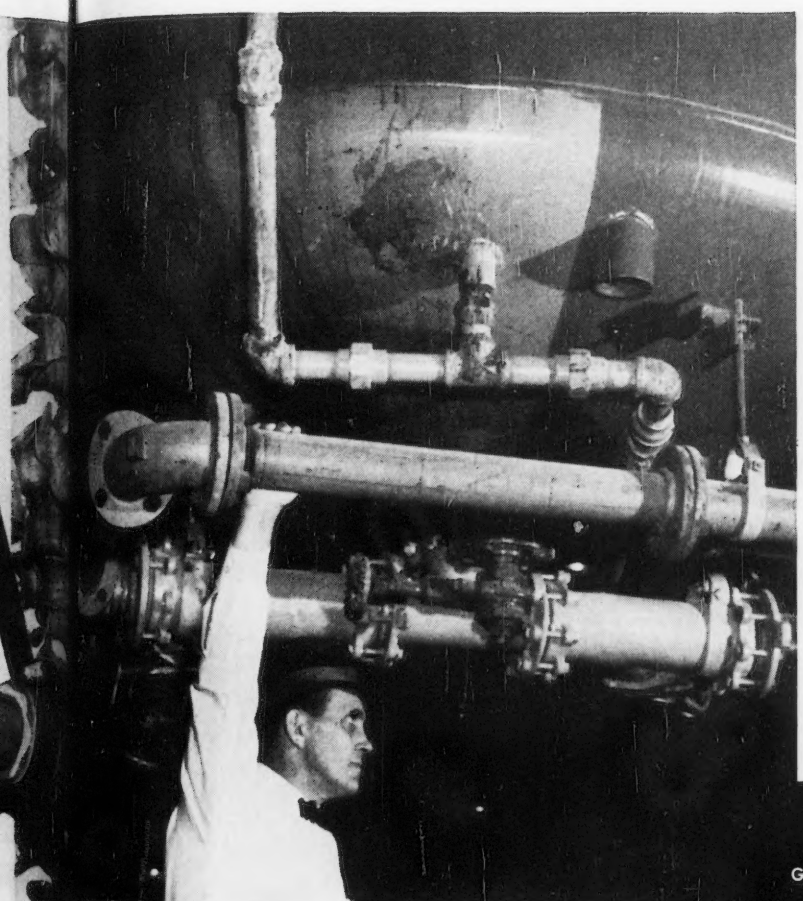
Inside and outside

High temperature resistance to a broad range of chemical reagents
Easily fabricated
Resistant to chemical atmospheres

Penton pipe and fittings, used in combination with other readily available Penton components for chemical processing, now make it possible to design a complete anti-corrosion system based on this versatile high temperature thermoplastic. Write for your copy of "The ABC's of Penton for Corrosion Resistance," which rates Penton's performance when ex-

**Hercules trademark for chlorinated polyether*

E IS BEST FOR YOU?

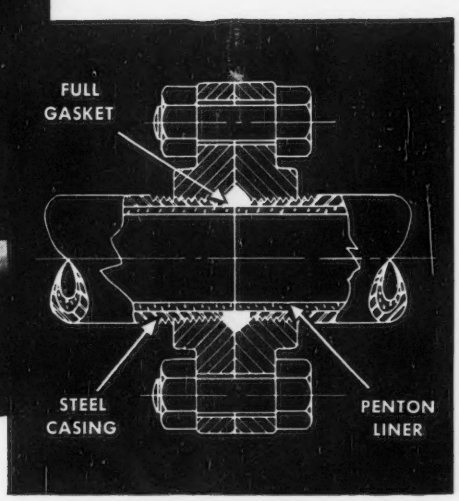


This 3″ Penton-lined pipe carries a chlorinated product in carbon tetrachloride, 0.1% to 3% hydrogen chloride, less than 0.1% chlorine, and occasional saturation with water, at temperatures ranging from 165°F. to 185°F. It shows no change after more than 10 months in continuous use.

Penton-lined pipe by Saran Lined Pipe Company, Ferndale, Michigan.

LINED PENTON PIPE:

Steel pipe with a heavy Penton lining, available in sizes from 1″ to 6″ I.P.S. outside diameter, in lengths up to 10 feet. Joined by flanged gasket connection (see diagram below), it can be cut and fitted in the field without difficulty. Combines the outstanding high temperature, corrosion resistance of Penton with the structural strength of steel.



posed to over 280 different chemicals and chemical reagents. Complete information on current sources for Penton products is listed in "The Penton Buyer's Guide," also available upon request.

THE STRENGTH OF STEEL

and the properties of Penton

Excellent corrosion resistance at elevated temperatures
Economically installed
Safe, durable, and strong

Cellulose Products Department

HERCULES POWDER COMPANY
INCORPORATED

Wilmington 99, Delaware

CP60-8

BOOK NEWS

Residual Oil Ash Corrosion Problem— A Review and Bibliography for Residual Fuel Oil Ash Corrosion. 16 pages, 8½ x 11 inches, paper. 1960. Publication 60-6. The National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas. Per copy, NACE members, $2.50; non-members, $2.00.

A summary of the history of corrosion caused by the combustion products of residual oil, including evaluation of materials of construction, protective coatings solutions, oil-additive solutions. There are 57 references and a bibliography. The bibliography consists of titles of 272 articles on the subject published 1919-1959 inclusive.

Photomicrography of Metals. 44 pages, 5½ by 8½ inches, paper. 1959. Publication No. P-39. Eastman Kodak Company, Rochester 4, N. Y. Per copy, 50 cents.

Designed as a reference guide for metallurgists, this data book can also serve as a short course in photomicrography for metallurgists interested in reviewing latest techniques in this field. Illustrated with photographs, charts and graphs, the book contains six major sections including detailed information on the metallographic microscope, illumination, filters in metallography, photographic materials, exposure determination and methods of processing and printing. Also has a bibliography.

Stress-Corrosion Cracking of Austenitic Chromium-Nickel Stainless Steels. 92 Pages, 8½ x 11, paper. March, 1960. American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. Also available from National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas. Per copy, ASTM and NACE members $4.80; others $6.

A report sponsored jointly by the American Society for Testing Materials Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys and NACE Unit Committee T-5E on Stress-Corrosion Cracking of Austenitic Stainless Steels. Part I consists of a review and discussion of 129 case histories from 24 sources experiencing stress-corrosion cracking of austenitic stainless steels. Part II covers information on current research activity obtained from numerous domestic and foreign sources and a review of the present knowledge of the basic mechanism of the phenomenon.

Of particular interest to companies concerned with stress-corrosion cracking is the summary of the reports. A comprehensive bibliography and abstracts covering the years 1935-59 inclusive occupies the last 24 pages of the book.

Chemical Patent Microcards

Microcards are available on chemical patents and patents dealing with the pulp and paper industry. The chemical patents are available from Godfrey Memorial Library, Middletown, Conn. Pulp and paper patents can be obtained from the Institute of Paper Chemistry, Appleton, Wis.

BLACK CARPET OF BUTYL RUBBER is being placed over the foundation of the 44-story Humble Oil & Refining Company building under construction in Houston, Texas. The butyl sheeting will serve as a water barrier for the building's foundation. The workmen are rolling the sheet over a thin concrete seal slab. A seven-foot thick steel-reinforced concrete slab will be laid on the butyl cushion. Foundation sides and retaining walls above will be encased by the membrane also.

Butyl Rubber to Be Water Barrier for Building Foundation

A black carpet of butyl rubber has been spread in the construction of the 44-story Humble Oil & Refining Company building in Houston, Texas, to serve as a water barrier for the foundation.

Almost 60 feet below street level, the ⅛-inch butyl sheet, produced at Humble's Baytown refinery and manufactured by other firms, was rolled over a thin concrete seal slab. A seven-foot thick steel reinforced concrete slab will be laid on the butyl cushion. Foundation sides and retaining walls also will be encased by the membrane.

Foundation of the Humble building is being constructed at an unusual depth in an area of water-bearing sands, where the permanent water table is only 18 feet below the surface. The building will have a four-level basement.

After the thin concrete seal slab is laid, the butyl sheet is unrolled, custom cut and sections joined by a flap seam with vulcanizing cement.

This method of sealing the foundation also will be used for the building's garage to be erected opposite the office building.

Salt Water Conversion May Give Power and Minerals

Power and minerals may be two important products derived from new processes for treating salt water to obtain more usable water for this country, according to a talk given at a recent ASME meeting by Allen Cywin, assistant director of demonstration plants, Office of Saline Water, U. S. Department of the Interior.

One promising possibility is a combination nuclear plant taking deuterium from the sea and producing fresh water and plutonium. Another combination steam generated power-water station would have most of the cost of its fuel and production charged off to power generation. Power generation produces steam that helps convert the water, thus lowering the cost of water conversion.

Drinkable water may be produced from moderately salty sources for about 30 to 50 cents per 1000 gallons by a process known as electrodialysis, according to H. R. Drew, research director for Texas Electric Service Co., Fort Worth, Texas. Electrodialysis is a relatively simple process and does not require large pieces of machinery or complicated heat exchange mechanisms. Permeable membranes are placed in water between electrodes. When a current is run through the electrodes, electrically charged particles of salt move to one electrode. The membrane which allows only one way traffic prevents them from moving back into the water solution again. One stream of water loses the salt; another stream picks it up and becomes more concentrated.

Battelle Helps Develop First Gas Cooled Reactor

More than four years of materials research at Battelle Memorial Institute have contributed to the successful development of the AEC's first gas cooled reactor experiment at the National Reactor Testing Station.

Battelle conducted critical experiments and formulated exact specifications for design of fuel elements and core configurations. Corrosion studies at Battelle also determined the materials and environmental conditions under which nitrogen could be used as the reactor coolant.

How to Set Up a Library

Any organization wishing to have professional advice on how best to set up a technical library can obtain competent advice on setting up, expanding, reorganizing or operating a special library or information service.

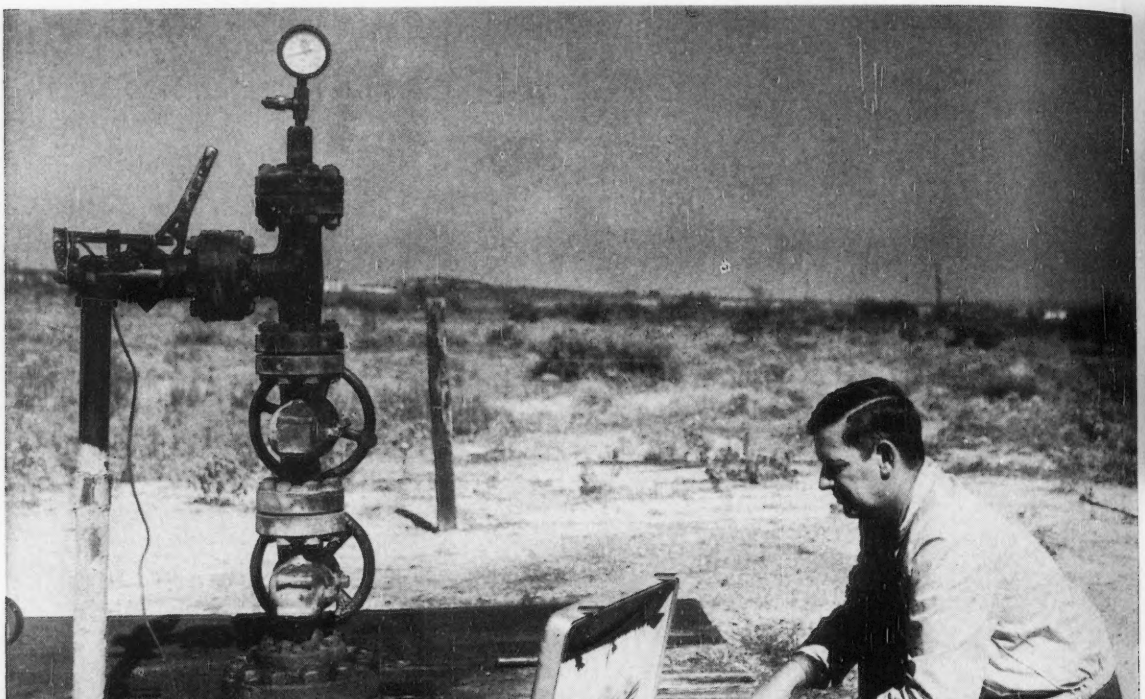
This advice can be obtained from the executive secretary of Special Libraries Association, 31 East 10 St., New York 3, N. Y.

...when it comes to corrosion.

Start by using Allied Chemical 34Yc Cold Coating #134 and Cold Tar Paint #110. Both items offer high-quality, low-cost protection against metal and masonry corrosion. 34Yc is excellent for all surfaces exposed to highly corrosive conditions, extreme moisture, or acid and alkali fumes. It's also an ideal coating for tanks, pilings, structural steel, underground pipes and units. Coal Tar #110 is preferred for outdoor frames and posts, safety and sprinkler piping, transmission towers, general railroad work. If your industrial distributor is not currently stocking these products, write to Industrial Tar Products Department.

PLASTICS AND COAL CHEMICALS DIVISION
40 Rector Street, New York 6, N. Y.

Allied Chemical



A Cathodic Protection Service engineer using CPS instruments is running a Current-Potential curve on one of 115 well casings in West Texas to obtain essential cathodic protection design data. These instruments were developed through extensive field experience and research.

FACED WITH SERIOUS EXTERNAL casing corrosion, the West Texas operator of these 115 wells selected Cathodic Protection Service to design and install the most economical protective system consistent with quality materials and workmanship . . . *ALL ON NEGOTIATED BASIS.*

Well casing protection is just one area of this specialized engineering field in which owners and operators have come to realize that competitive bidding involving engineering judgment, know-how and integrity can become a frustrating and expensive experience.

Cathodic Protection Service offers something that can neither be standardized nor specified!

Cable Address — CATPROSERV

CPS **cathodic protection service**

P. O. Box 6387 Houston 6, Texas JAckson 2-5171

CHICAGO
122 S. Michigan Blvd., Rm. 964
WEbster 9-2763

CORPUS CHRISTI
1620 South Brownlee
TUlip 3-7264

NEW ORLEANS
1627 Felicity
JAckson 2-7316

ODESSA
5425 Andrews Hwy.
EMerson 6-6731

TULSA
4407 S. Peoria
Riverside 2-7393

5B12

NOT A SPACE MAN, A METAL WORKER—A modified design of future space suits has been used for this metal worker inside a controlled atmosphere room where refractory metals such as molybdenum, columbium, tantalum, tungsten and their alloys are milled. The controlled atmosphere makes it possible to mill the metals at hot working temperatures of 4000 F in an inert argon atmosphere so that no oxidation, diffusion or contamination occurs.

Higher Quality Refractory Metals Milled Under Inert Atmosphere

Production has begun of refractory metals of unusually high integrity for future hypersonic aircraft and aerospace weapons in a special inert fabrication facility called InFab at Universal-Cyclops Steel Corp., Bridgeville, Pa. Purpose of the InFab is to mill refractory metals such as molybdenum, columbium, tantalum, tungsten and their alloys without oxidation or contamination. InFab was designed and constructed by Universal-Cyclops' Refractomet Division in cooperation with the Department of the Navy, Bureau of Naval Weapons.

These refractory metals currently are being produced on specialty steel mill equipment which does not permit full use of the metals' inherent properties. These metals should be hot-worked at temperatures twice the 2300 F now possible in conventional mills. Molybdenum at such high temperatures oxidizes catastrophically, and all refractory metals are contaminated by elements in the air.

Controlled Atmosphere

Thus, to prevent contact with normal atmosphere during processing at high temperatures, the InFab enclosure is filled with inert argon gas. Inside the enclosure are an impactor, rolling mill, furnaces, a 10-ton crane and space for additional equipment. Forging and rolling of these refractory metals is performed at temperatures to 4500 F in the protective atmosphere of argon gas.

This equipment is controlled from consoles outside the enclosure. Each console has a full view of the operations it controls through a special glass window which shields out harmful ultraviolet rays emitted from the white-hot metal. The crane is used to transfer the metals from one piece of equipment to another.

Space Suit Used

Some functions must be done by personnel inside the enclosure. For this, the men are dressed in a modified design of future space suits, as shown above. The suit has five layers and is gas-tight. The reflective aluminized outer garment provides shielding from thermal and ultra-violet radiation.

An insulated knitted undergarment is worn under a ventilation suit that permits complete distribution of air around the body at 8 to 10 cubic feet per minute at 74 F, 40 percent humidity. A second insulating garment is worn and a gas-tight blouse and trouser assembly, permitting a high degree of mobility. The head piece is of fiber glass and plastic, designed to be non-fogging. Special gloves and boots complete the assembly.

An air supply and cooling unit is carried on the back. Once within the enclosure, the men connect their communications and power supply line into conveniently located outlets.

Men, material and equipment move in and out of InFab through three locks which are vital to maintenance of the high argon purity required and to keep loss of gas to a minimum. Argon is maintained at a pressure just above atmospheric to prevent contaminating air from leaking in. Two personnel "crash" doors have been built for safety.

Refractory metals formed from metal powders by compaction and sintering into electrodes are melted into high quality ingots in a consumable electrode vacuum arc furnace. This furnace produces 12-inch diameter ingots, 70 inches long, weighing up to 3000 pounds. Inside the enclosure, ingots are broken into billets or sheet bar at temperatures to 4500 F under the force of a horizontal impactor. The ingots are heated in induction furnaces. Normal product of the impactor is 4-inch round cornered square billets and sheet bars 2-inches by 10-inches in cross section.

If further processing is desired, the billet and sheet bar is transferred to the rolling mill area in the enclosure. They are heated in a graphite lined indirect induction furnace. A molybdenum liner inside the furnace protects the metal from reaction with the graphite.

•

The 1960 Corrosion Control Short Course sponsored by the NACE Central Oklahoma Section will be held Sept. 28-30 at the University of Oklahoma, Norman.

Stainless Steel Alloys Solve Corrosion on Truck Brake Device

Problems of corrosion, warping, leaking, cracking and excessive fabrication costs in an auxiliary truck braking device were solved by use of stainless alloy castings. These problems previously made the brake device impractical.

Developed by the Power Brake Equipment Co., Portland, Ore., the compression brake is designed for use on diesel and gasoline engines to provide increased safety and reduce operating and maintenance costs. It operates independently of air or mechanical brakes. When the truck descends a grade, a butterfly valve automatically closes to begin pressure build-up in the exhaust manifold when the foot throttle is released. Bolted directly to the manifold or welded compactly into the exhaust pipe between the manifold and muffler, the brake restricts engine exhaust and builds a back pressure of 40 to 50 psi in the exhaust manifold. Thus converting each cylinder into a low pressure air compressor, the braking device introduces a retarding force against piston head areas at least equal to the engine's horsepower output.

Type HH heat resistant alloy (Alloy Casting Institute designation) solved the corrosion caused by hot exhaust gases in the manifold and also eliminated the problem of high temperature warping experienced with wrought alloys. One-piece casting also was possible with the Type HH alloy, thus reducing fabrication costs.

Sales Training Program Begun in Stainless Steel

A one-million dollar sales training program begun by Republic Steel Corporation is designed to help stainless steel distributors and salesmen understand stainless fabricating, production control and application problems encountered by the customer.

A series of color films have been produced as part of the program. They include such titles as "The New World of Stainless Steel" and "A New Look at Modern Living." Plans are being made for showing of the films to clubs, schools and other interested groups. Other films on machining and fabricating are being produced.

1959 Engineering Index

The annual edition of the Engineering Index for 1959 is available now in bound volumes. The Index is a guide to periodical technical literature in which CORROSION Magazine is indexed.

Additional information can be obtained by writing Engineering Index, Inc., 29 West 39th St., New York 18, N. Y.

Equipment Services NEW PRODUCTS Materials Literature

Coatings, Metallic

Nickel-over-steel protective coatings for steel pipe are described in a new brochure available from M. L. Sheldon & Co., Inc., 350 Lexington Ave., New York 16, N. Y. Also included is information on the Niphos process for applying bonded metallic coatings on the inside and outside of pipe and tubing without the use of electric current.

•

Tabular information on corrosion rates of zinc on galvanized sheets is given in a new brochure titled "Industrial Procurement Galvanized Steel Sheets" available from the American Zinc Institute, Inc., 60 East 42nd St., New York 17, N. Y. The table shows a comparison of galvanized steel sheet life expectancy in 5 environments with two thicknesses of galvanized coating in comparison with unprotected steel.

Coatings, Organic

Worn, uneven wood and concrete floors can be restored to a level, wear and water resistant surface by application of Flintmastic, according to a booklet available from Flintkote Company, 30 Rockefeller Plaza, New York 20, N. Y. Non-brittle and semi-flexible, the material is claimed to resist indentation from loading and abrasion from wear.

•

Proper repair and preparation of concrete floors before application of organic protective coatings are described in detail in Bulletin 1019 available from Carboline Company, 32 Hanley Industrial Court, St. Louis 17, Mo. Included is a chart listing nine conditions or stages of concrete floors commonly found in various plants. After each condition, the recommended repair method is explained. Repair of concrete cracks and expansion joints is shown in diagrams. Procedure for determining pH of concrete also is given.

•

A vinyl organosol coating is being used to maintain the new appearance of metal partitions and counters in the newly constructed Black Rock Office of Marine Trust Company at Buffalo, N. Y. The coating used was Armorhide, an organosol coating made from Bakelite vinyl resins, which is designed to resist perspiration, scratching and abrasion. It also was used on partitions between tellers' cages and administration area. This coating also has been used for computers, tabulators, typewriters, electronic equipment, dashboards, television sets and outdoor furniture. Armorhide is marketed by John L. Armitage and Company, Newark, N. J.

Filters

Multiple-surface porous stainless steel filters are described in a bulletin available from Micro Metallic Division of Pall Corporation, Glen Cove, N. Y. Information is included on filters for wide ranges of flow rates, temperatures, pressures and slurries. A description of Rigimesh, a furnace welded woven wire mesh, includes characteristics which make it suitable for specialized applications.

•

With no moving parts, electrical wiring or replaceable filter elements, the Hydro-Volute Scrubber is designed to have a long service life and develop high efficiencies on a wide range of fumes, dust and odor problems, according to the manufacturer, Johnson-March Corp., 3018 Market, Philadelphia 4, Pa. Scrubbers are available in capacities from 1000 to 60,000 cfm.

Instruments

Platform-type bench scales for heavy duty general weighing operations are available from Exact Weight Scale Co., 538 East Town St., Columbus 14, Ohio. The scales are designed with a minimum of moving parts and have overload and bumper springs to eliminate excessive shock in loading and unloading.

•

Specially plated for brine and sweat resistance, a new precision 12-hour stopwatch designed for panel and dash board mounting is manufactured by Heuer Timer Corporation, 441 Lexington Ave., New York 17, N. Y. For process and research instrumentation which requires decimal data, an alternate dial face is provided with extra peripheral divisions in hundredths of a minute.

•

Accurate assessment of heating or cooling costs on basis of recorded consumption can be made by use of a new sweep balance Btu meter, according to Air Conditioning Equipment Corporation of New York City, United States and Canadian distributor of the Pollux mechanical Btu meter. It requires no amplifiers and uses electrical resistance thermometers and an electromechanical computing device. Turbine type flow meters are used for accurate checking over a full range of flow rates.

Insulation

Adhesives, coatings and weatherproofings for insulation applications are described in Bulletin ICA available from Insul-Coustic Corp., 42-23 54 Road, Maspeth 78, N. Y. It also gives a simplified method of selecting the proper product for insulation jobs and lists typical applications.

•

Acoustical insulation with vapor sealing properties has been developed by Fibrous Glass Products, Inc., Alpha Plaza, Hicksville, Long Island, N. Y. The insulation is made of molded fibrous glass. Vapor sealing is made effective by pasting asbestos cloth over the insulation, then painting the entire assembly with a vapor-proof paint.

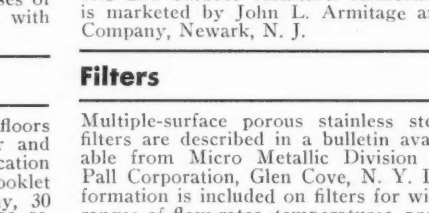
Lubricants

Designed to overcome seizing and galling that take place in conditions of extreme pressure where ordinary lubricants often fail, Anti-Seize is a new lubricant developed by Bel-Ray Company, Collingwood Park, N. J. It also is designed to prevent corrosion of parts exposed to most acids and alkalies, water and steam.

•

Dirt and abrasive contamination of greases and brushes for grease application can be eliminated by use of a plastic jar with an applicator brush for Molykote G, according to Alpha-Molykote

Where Other Materials Fail . . . duVerre Assures Lasting



duVerre Stacks & Ductwork Destined for a Leading Chemical Company

PROTECTION FROM CORROSION

du Verre recognizes that many materials play an important part in corrosion control. However, du Verre's reputation is built on the effective, lasting performance of its construction under corrosive conditions where other materials have failed.

du Verre fabricates process equipment such as ducts, stacks, hoods, tanks, covers of Resin Bonded Fiberglass. The prime advantage of du Verre over other materials is homogeneous construction. Unlike coatings and linings, du Verre gives complete corrosion control through and through — both inside and out — even under severe conditions of erosion. du Verre construction is also light in weight. This minimizes shipping and erection costs.

Whatever your corrosion problem, chances are du Verre can solve it. We are equipped for special fabrication to suit your process requirements exactly. Write today for Bulletin No. 101 for complete facts.

du Verre inc. du Verre, Incorporated
Box L • Arcade, New York

duVerre . . . First in Quality for Complete Corrosion Control with Reinforced Plastics.

Corp., 65 Harvard Ave., Stamford, Conn. Molykote G is a lubricant designed for extreme pressure applications. The jar is made of oil resistant molded plastic with a protected well in the center for storing the brush free from possible contaminants when the cap is replaced.

Mergers

H. K. Porter Company, Inc., diversified Pittsburgh industrial manufacturing concern, recently purchased over 90 percent of the stock of the Patterson-Sargent Company of Cleveland, Ohio, manufacturers of paints for home and industry.

•

Coast Paint and Lacquer Company of Houston, Texas, manufacturer of Copon coatings for pipelines, has merged with Reliance Varnish Company of Louisville, Ky. Reliance manufactures wood finishing materials, lacquers and decorative metal coatings.

•

Haveg Industries, Inc., Wilmington, Del., has agreed to purchase equipment and inventory of the Blow-O-Matic Corporation, Bridgeport, Conn. The new acquisition will be operated as the Blow Molding Division of Haveg Industries and will be located at 405 Central Ave., Bridgeport 1, Conn.

•

National Malleable and Steel Castings Co., Cleveland, Ohio, has acquired ownership of Hill, Hubbell & Company, also of Cleveland. Hill, Hubbell applies protective coatings to pipe at its plants near major steel mills. It will be operated as a wholly-owned subsidiary.

Metals, Exotic

A new low-cost process for manufacturing titanium powdered metal parts has been developed by the Clevite Corporation, 540 East 105th St., Cleveland 8, Ohio. Components made by this process show comparative corrosion resistance and strength to that of wrought products, according to Clevite.

•

A convenient chart showing the complete properties of tungsten, tantalum, molybdenum and columbium can be obtained from Fansteel Metallurgical Corp., Dept. CO-5, Metals and Fabrication Division, North Chicago, Ill. Reverse side of the chart has a temperature chart for converting degrees from Fahrenheit to Centigrade or vice versa.

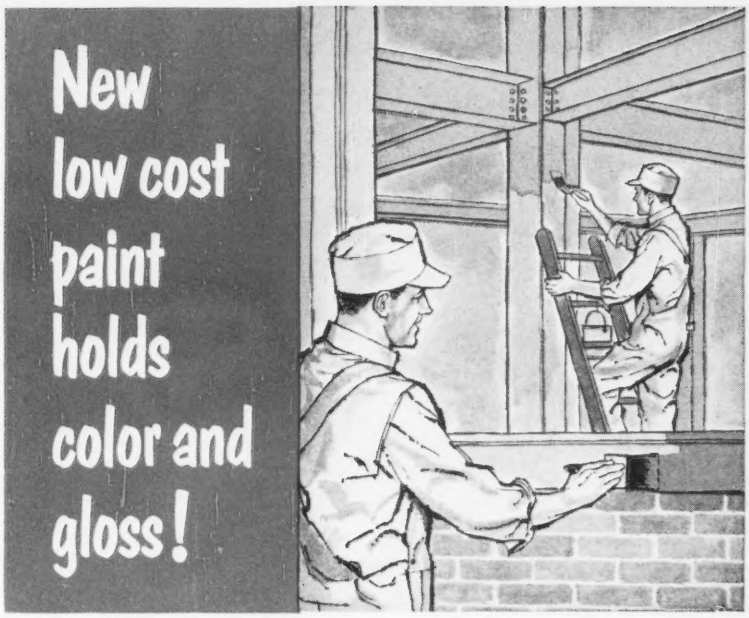
Plastics

A vinyl latex designed by B. F. Goodrich Chemical Company has been incorporated in new water-base paints for outdoor use. The latex, Geon 450X3, combines chemical resistance and weatherability of the vinyls with the flexibility of acrylics, according to B. F. Goodrich. Paint formulated with the latex is claimed to have remained uncracked after five years' exposure in northern Ohio with similar results after three year exposures in Florida, California and Arizona.

•

A 31-inch marine propeller molded of nylon has been manufactured by Auburn Plastics, Inc., Auburn, N. Y. Molded of a polycarbonate resin, the propeller weighs 19 pounds; it would replace a bronze propeller weighing over 150 pounds. The nylon propeller has tough-

(Continued on Page 58)



VALDURA DURAWEAR

Higher in Solids--gives higher film build . . . cuts maintenance painting costs

Money-saving Durawear not only has top color and gloss retention, it gives extra protection to surfaces for many years. Featuring a linseed oil modified alkyd vehicle, Durawear has better brushability than straight alkyd enamels. It is very easy to paint on irregular surfaces since the consistency prevents running off from sharp corners. Use Valdura Durawear on steel, wood or masonry—indoors or out—as illustrated above, on fire escapes, wall surfaces, storage tanks, and wherever protection from elements of weather is desired. Available in five attractive colors.

VALDURA PAINTS THAT ENDURE

Please send me complete information and color chips on Valdura Durawear.

VALDURA HEAVY DUTY PAINT DIVISION
AMERICAN-MARIETTA CO.
101 E. Ontario St., Chicago 11, Illinois

NAME _____

COMPANY _____

CITY _____ STATE _____

NEW PRODUCTS

(Continued From Page 57)

ness, durability and freedom from corrosion and attack from barnacles, according to Auburn.

•

Materials, equipment, design assistance and engineering information for production of high-quality urethane foams are described in a new booklet offered by Isocyanate Products, Inc., 900 Wilmington Road, New Castle, Del. The booklet deals with use of flexible and rigid foam-in-place resins for low temperature insulation, shockproof packaging, comfort cushioning, marine flotation, encapsulation of electronic components and other applications.

•

V-belts made with neoprene and special high capacity tensile cords are being produced after ten years of tests by the Gates Rubber Company, 999 South Broadway, Denver 17, Colo. The neoprene belts are designed to have almost 50 percent smaller cross sections than conventional belts with as much as three times the horsepower capacity. Neoprene is manufactured by Du Pont's Elastomer Chemicals Department.

•

The Penton Buyer's Guide, a complete listing of manufacturers of chemical processing equipment made with Penton chlorinated polyether, is available from Hercules Powder Company, Inc., Wilmington 99, Del. Equipment listed includes machined parts, pipe and fittings, pumps, sheet and stock shapes, tank liners, tubing, valves, welding equipment and coatings.

•

Production of large plastics shapes by fusion of powdered thermoplastic in inexpensive molds will be handled by five U. S. companies using the Thermofusion process employed in Europe for fabrication of articles as large as 10-foot pleasure boats and 500-gallon tanks. Thermofusion is a service mark of the Spencer Chemical Company, Dwight Bldg., Kansas City 5, Mo. Spencer will supply special grades of powdered polyethylene used in the process. The U. S. companies scheduled for plastic production with the process are American Agile of Cleveland, Ohio, Amos Molded Plastics, a division of Amos-Thompson, Inc., of Edinburg, Ind., Loma Plastics of Fort Worth, Texas, Rubbermaid of Wooster, Ohio, and Space Structures, Inc., of Chanhassen, Minn.

•

Fretting corrosion particles, which caused bearing failures in a business machine calculator, were eliminated by making the corroded part of Delrin acetal resin, a rigid polymer of formaldehyde produced by Du Pont at Parkersburg, W. Va. The corroded part, called an interposer link, transmits an impulse from a punched card into the data processing machine. Formerly made of beryllium copper at a cost of $630 per thousand units, it is now being injection molded of Delrin at $120 per thousand. The change to a thermoplastic material also has increased the normal service life of the part from five million cycles to 80 million, according to Du Pont. The part is molded by B & B Plastics of Oakville, Conn.

•

Stainless steel panels used for the curtain wall of the new Union Carbide Building in New York City were protected from general construction and weather hazards during the building's erection by a plastic made from a viscous water base compound. After completion of the building, the plastic film is stripped from the steel panels which have a black matte finish to prevent undesirable sun reflection.

Pumps

A low cost, compact canned pump with stainless steel wetted parts has been developed by Fostoria Corporation's Chempump Division, Buck & County Line Roads, Huntingdon Valley, Pa. Known as Dynapump Model 480E, the new unit is claimed to be leak-proof, weighs less than seven pounds and will handle capacities to 840 gph. It is suitable for temperatures to 220 F, pressures to 150 psi and specific gravities to 1.5.

•

Simultaneous transfer and measurement of fluid and semi-fluid products have been designed in a positive displacement pump developed by the Pump Division of Waukesha Foundry Company, Waukesha, Wis. The MFC-250 metered flow control pump is available in two models: gearhead with cycle monitor or varidrive with tachometer. They are made of stainless steel.

•

A high pressure pump incorporating new techniques of using stainless steel parts is available from Sonic Engineering Corporation, 146 Selleck St., Stamford, Conn. Two sizes cover a capacity range from 1 to 30 gpm, pressures to 400 psi and temperatures to 180 F or higher with special seal materials. Use of double helical gears that run in contact with each other give high efficiency and eliminate trapping and pulsing, according to the manufacturer.

Tests

Panelized walk-in environmental rooms with two temperature ranges are being fabricated by Labline, Inc., 3070-82 West Grand Ave., Chicago 22, Ill. The ranges are ambient to 140 F and 0 to 140 F. The rooms are shipped disassembled for easy access through narrow doorways. The rooms are available in sizes from 6 x 6 feet to 6 x 12 feet. Additional information is given on Bulletin No. 166 available from Labline.

•

A new accelerated corrosion test for steel is being distributed by Eastern Scientific Co., 267 Plain St. Providence, R. I. Supplied as two separate solutions, Rustex can be mixed fresh to provide a readily reproducible corrosion test. The manufacturer recommends Rustex for evaluating panels and parts treated with chromate conversion coatings, black oxide, phosphatized coatings, plastisols, polyester, vinyl, epoxy, lacquer and most electroplated metals.

Valves

Light weight, high strength and chemical resistance are characteristics claimed for the new polypropylene throttlable gate valves available from Vanton Pump and Equipment Corporation, Hillside, N. J. The plastic valves are designed to have resistance to most solvents, greases, oil and most common acids at temperatures to 185 F. They are available in sizes from ½ to 2-inches with socket-weld, flanged or screwed ends.

•

Solenoid operated pinch-type valves that can be used for metering, sampling or on-off control in applications involving corrosive fluids, slurries, dry powder or sanitary products have been developed by RKL Controls, Inc., Hainesport, Industrial Park, Hainesport, N. J. The valves can be operated manually or from programmers, alarms, timers or automatic sensing instruments.

•

Hills-McCanna ball valves and diaphragm valves will be distributed by Metal Goods Corporation and Geigher Pipe & Supply Company, both of St. Louis, Mo.

HANDI-BLAST PORTABLE SANDBLASTER

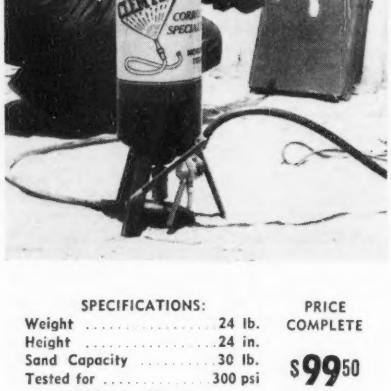
At Last!!

HANDI-BLAST

A small pressure sand blasting machine that uses no more air than a paint spray gun!

Designed to clean small units and areas quickly and efficiently.

Provides excellent surface preparation for Painting, Inspection, Metallizing, etc.



SPECIFICATIONS:

Weight	24 lb.
Height	24 in.
Sand Capacity	30 lb.
Tested for	300 psi

Write for Literature

PRICE COMPLETE $99.50

Complete Corrosion Control Equipment and Supplies

CLEMTEX, LTD.

Phone ORchard 2-6661

P. O. Box 15214 Houston 20, Texas

MEN in the NEWS

R. F. Protiva has been named manager of the Cleveland plant of Heil Process Equipment Corp., 12901 Elmwood Ave., Cleveland 11, Ohio.

•

Gail W. Kemp, NACE member, has been elected chairman of the San Antonio Sub-section of the American Society of Mechanical Engineers. He is a mechanical engineer in utilities at Randolph Air Force Base, San Antonio, Texas.

•

Lawrence C. Anderson has been appointed Chicago district field representative for Air-Maze Corporation, 25000 Miles Ave., Cleveland, Ohio.

•

Bernard W. Bernstrom has joined Jones & Laughlin Steel Corp., 3 Gateway Center, Pittsburgh 30, Pa., as a mechanical engineer in the Raw Materials Division.

•

Robert Stein and **John Boghosian** have been appointed members of the technical staff at Space Electronics Corp., 930 Air Way, Glendale, Cal. Two other recent appointments to the technical staff are **Frederick Brugma** and **Richard George.**

•

Joseph E. Burke, manager of the Ceramic Studies Section at the General Electric Research Laboratory, Schenectady, N. Y., has been elected chairman of the Basic Science Division of the American Ceramic Society.

•

Herschel H. Cudd, vice president in charge of research and development at American Viscose Corp., 1617 Pennsylvania Blvd., Philadelphia 3, Pa., has been named president of AviSun Corporation, a new jointly owned affiliate of American Viscose and Sun Oil Company.

•

Leo C. Damskey has been promoted to sales manager of the Midwest district for the Metalworking Chemicals Division of Amchem Products Inc., Ambler, Pa.

•

Two field engineers have been appointed by the abrasives division of Elgin National Watch Company, Elgin, Ill. **Edward Dalka** will cover western Pennsylvania; **Charles Swanson** will cover Rhode Island, Massachusetts, Vermont, New Hampshire and Maine.

•

Roger D. Freriks has been appointed manager of the Ditzler Color Division in Detroit for Pittsburgh Plate Glass Co., 632 Fort Duquesne Blvd., Pittsburgh 22, Pa. **John F. Green** has been appointed general manager of Pacific Coast Operations, Paint and Brush Division for the company with headquarters in Torrance, Cal.

•

Two men have been added to Hills-McCanna Company's field sales staff: **R. D. Brown** has been named western regional manager at 110 South Euclid, Pasadena, Cal., and **William Loomis** sales engineer with offices at 211 Joaquin St., San Leandro, Cal.

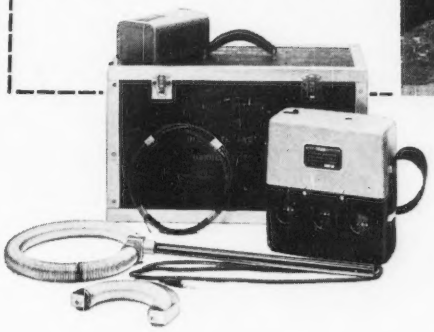
•

Kenneth W. Jones has been named sales manager for Tejas Plastics Materials Supply Co., 1838 Eighth Ave., Fort Worth, Texas.

(Continued on Page 62)

Maintain Coating Application Standards

INSPECT WITH A TR HOLIDAY DETECTOR!



EP HOLIDAY DETECTOR
Portable, "damp-climate," pulse type holiday detector for coated surfaces.

To obtain maximum protection and hold maintenance costs to a minimum, inspect protective coating with a Tinker & Rasor Holiday Detector and make repairs before backfilling. Minutes spent inspecting the pipe with a Tinker & Rasor Holiday Detector while the ditch is open can save days making repairs later on. Clearly, if protective coating is desirable, the best possible protective coating is *most* desirable.

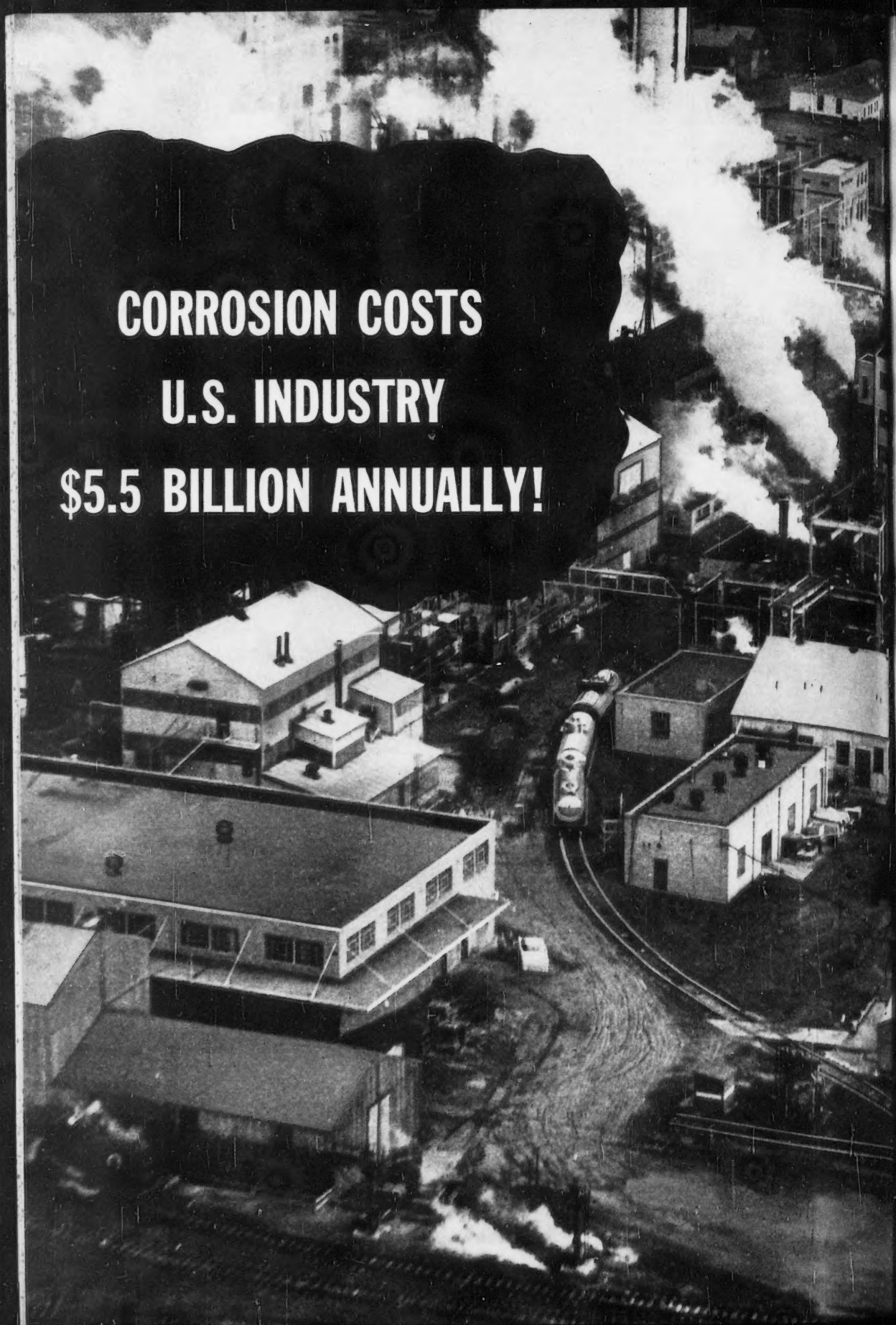
Every holiday in your protective coating increases the current requirements of cathodic protection. The result is constantly increasing maintenance costs.

Insure your pipeline's future with inspection by Tinker & Rasor Holiday Detectors. Write today for technical data and bulletin.

Engineering Note:
To insure a successful application, your specification should include TR Holiday Detector inspection. Write for specification guide.

DISTRIBUTORS:
Falcon Line Products Corp., Kearny, New Jersey
Crutcher-Rolfs-Cummings, Inc., Houston, Texas
Remco Manufacturing Co. Inc., Tulsa, Oklahoma
Bob Herrick, New Cumberland, Pennsylvania
Canadian Equipment Sales & Service Co. Ltd., Edmonton, Alberta, Canada
Export Agent: Frazar & Hansen Ltd., San Francisco, Calif.

Quality control for coating application
TR TINKER & RASOR
417 Agostino Road, P.O. Box 281 • San Gabriel, California



Corrosio
can indu
corrosion
or $9,468
costing
More
complete
coatings
corrosion
20 diffe
specific
ordinary
Pitt

PITT

PITT

Nam
Com
Stre
City

Now You Can Control 97% of All Your Corrosion Problems with this Proven PITT CHEM® Coating System!

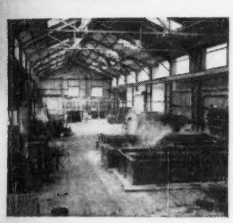
Corrosion is one of the biggest profit robbers in American industry today. It is conservatively estimated that corrosion costs U.S. industry $5.5 billion annually . . . or $9,468 per minute! How much is this enormous waste costing *your* plant?

More and more corrosion engineers are turning to the *complete* PITT CHEM System of thick-film, cold-applied coatings for efficient long-lasting protection against corrosion. The PITT CHEM system is composed of over 20 different coatings, each formulated to control a specific type of industrial corrosion—from the most ordinary to the most severe—at minimum cost.

PITT CHEM Tarset, Tarmastic and Insul-Mastic are tough, *heavy film* coatings that outlast conventional maintenance paints 10 to 20 times. You measure their protection in *decades*, not years. They can be cold-applied by brush, spray gun or roller. No other family of protective coatings can solve so *many* of your corrosion problems so *economically*.

For more information, mail the coupon below. Then consult your nearest PITT CHEM Distributor—he's listed in the "Yellow Pages." Or call Pittsburgh Coke & Chemical Company in Pittsburgh, New York, Chicago, Houston or Los Angeles. A PITT CHEM Corrosion Engineer will be glad to discuss your corrosion problems without obligation.

PITT CHEM TARSET®



The original, patented coal tar-epoxy coating, Tarset is being used throughout industry to solve corrosion problems that were once considered "impossible." This revolutionary cold-applied coating is ideal for the protection of underground storage tanks, pickling tanks, high temperature steam lines, waste tanks and similar equipment.

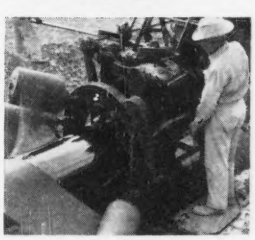
PITT CHEM TARMASTIC®

PITT CHEM Tarmastic coatings are a series of coal tar protective coatings designed to meet a wide variety of corrosive conditions at moderate cost. Their protective ability has been proven by years of service on concrete, stone and masonry surfaces, cooling towers, fan housings, tank exteriors, potable water systems and similar equipment.

PITT CHEM INSUL-MASTIC®

A series of high quality Gilsonite-asphalt mastics recommended for economical, long-lasting protection against moisture and atmospheric corrosion. Widely used as a weather and moisture barrier over metal buildings and equipment. Insul-Mastic insulating cork mastics provide good heat loss reduction and condensation control.

PITT CHEM PIPELINE ENAMELS



PITT CHEM Coal Tar Pipeline Enamels protect oil and gas transmission and distribution lines throughout the United States. These proven, high quality enamels are geared to meet a wide variety of underground service conditions and are backed by experienced technical field service.

Send for Your Free Copy of this

INDUSTRY CORROSION DATA FILE

Includes a survey of corrosion problems in general industry, data on PITT CHEM Coating Systems and a coating selector guide.

Name_____ Title_____

Company_____

Street_____

City_____ State_____

PROTECTIVE COATINGS DIVISION

PITTSBURGH CHEMICAL CO.

GRANT BUILDING PITTSBURGH 19, PA.

A Subsidiary of PITTSBURGH COKE & CHEMICAL CO.

1180

CORROSION ENGINEERS

Opportunity at

ESSO RESEARCH AND ENGINEERING COMPANY

Chief Technical Affiliate—
Standard Oil Company
(New Jersey)

The opportunity exists for a Corrosion Engineer to join a major oil company involved with all phases of the petroleum industry. His area of responsibility will involve corrosion mitigating methods applied to plant problems and the development of new methods in the laboratory. He will guide pilot plant and laboratory studies to determine the construction materials and corrosion control methods required on new processes. Some domestic and foreign travel may be required.

College graduate with high scholastic records and minimum 2 years experience in petroleum or chemical industry corrosion required. Must be familiar with corrosion mechanisms and corrosion mitigating methods.

Give full details of education, experience, desired salary and references. All inquiries will be considered promptly and held confidential.

Address replies to:
Mr. C. D. Gardei
Employee Relations—B

ESSO RESEARCH AND ENGINEERING CO.
P. O. Box 175
Linden, New Jersey

MEN in the NEWS

(Continued From Page 59)

Ray Knox has been appointed manager of the New England sales office for International Rectifier Corp., with offices at 17 Dunster St., Cambridge, Mass.

Glenn M. Herring has been appointed assistant to vice president of sales for Hanson-Van Winkle-Munning Company, Church Street, Matawan, N. J.

•

Walter E. Gregg has been elected vice president of technology for Crucible Steel Company of America, Pittsburgh 22, Pa.

POSITIONS WANTED AND AVAILABLE

Active and Junior NACE members and companies seeking salaried employees may run without charge two consecutive advertisements annually under this heading, not over 35 words set in 8 point type. Advertisements to other specifications will be charged for at $10 a column inch.

Positions Available

Corrosion Engineer—To head up and expand gas distribution corrosion control program. Please address resume of past experience, education and personal data to J. L. McAdam, Illinois Power Company, 500 S. 27th Street, Decatur, Ill.

Corrosion Engineer with 10 years of diversified chemical processing problem solving experience is required by a large multi-plant chemical organization. Will evaluate current methods and procedures and set specifications for new construction. Write Box 60—24, CORROSION.

WANTED: Graduate chemist or chemical engineer for product development of industrial maintenance coatings.

EXPERIENCE: Up to five years general industrial maintenance coatings formulation development.

DUTIES: Development and applications research of chemical and corrosion resistant coatings, epoxy plastics for structural applications and finishing systems for building maintenance. Must be able to meet and discuss coatings problems with sales personnel and customers and have supervisory ability or potential.

SALARY: Commensurate with experience, excellent benefits.

LOCATION: Truscon Laboratories, Inc. Division, Detroit, Michigan.

In reply, please indicate availability for an interview in Detroit, salary requirement, education and experience. Forward all replies in confidence to C. M. Jackson, Devoe & Raynolds Company, Inc., P.O. Box 328 Louisville 1, Ky.

Positions Available

GAS ENGINEER

Fast growing and progressive midwest natural gas utility, with over 16,000 customers is seeking an engineer with at least 3 or 4 years' gas utility operation experience since graduation to take a position in a supervisory capacity. Prefer man about 30 years of age with technical background and experience in corrosion and cathodic protection and with executive ability to supervise this type of work. Send full resume of experience, age and salary requirements. CORROSION, 60-18.

Positions Wanted

Successful, mature sales executive in bituminous, plastic and oleoresinous field, specializing in distributor training and relations. Travel no deterrent. Well acquainted Western U. S. and especially far West. Availability occasioned by merger. CORROSION, Box 60 - 20.

Corrosion Engineer—Experienced in protective coatings, construction procedures and cathodic protection for pipelines, marketing and storage facilities, plants and production equipment desires responsibilities with aggressive company. CORROSION, Box 60-22

Petroleum-Corrosion Engineer, B.S. 1952, experience in cathodic protection and oil field operations. Desire position, with growth potential, with oil or gas company. Will relocate. Age 35, married. Resume on request. CORROSION, Box 60—23.

GOODYEAR ATOMIC CORPORATION

Has Opening For Specialists In:

- ***Solid State Physics***
- ***Physical Chemistry***

and/or

- ***Electron Microscopy***

and

- ***Electron Diffraction***

To work on research and development projects in the fields of thin films, crystal perfection and corrosion.

SUBMIT RESUME AND SALARY REQUIREMENTS TO:

Employment Department
GOODYEAR ATOMIC CORPORATION
P. O. Box 628
Portsmouth, Ohio

TECHNICAL COMMITTEE ACTIVITIES

Methods of Sampling Corrosion Products Discussed by T-3B

Methods of sampling corrosion products, chemical cleaning and new analytical techniques were discussed at the Dallas meeting of Technical Unit Committee T-3B (Corrosion Products).

Hugh L. Logan of the National Bureau of Standards, Washington, D. C., presented general methods for sampling corrosion products. Specific methods of separating phases included acid, wash, alkali wash, magnetic techniques and mechanical probing. He emphasized that complete identification of the corrosion mechanism requires extreme care in sampling with special attention on stratification of the corrosion products.

R. B. Rosene of Tulsa, Okla., gave a presentation of chemical cleaning as used in industry to remove corrosion products and deposits which reduce the useful life of equipment. Composition of the material to be removed must be determined as whether it is a corrosion product or an operational deposit so that the proper method of cleaning can be used. Typical cleaning solutions include inhibited acid, fluoride salts and detergents. Many applications require elevated temperatures from 150 to 250 F. At the higher temperature, organic inhibitors have been used. Foam techniques have been developed which reduce the quantity of solution needed for cleaning large tanks.

A discussion of new analytical techniques was led by D. A. Vaughan, T-3B vice chairman. Microchemical methods discussed included wet chemistry on microquantities, staining techniques, spectrographic analysis and X-ray fluorescence on a macro and micro scale. He emphasized the importance of X-ray and electron diffraction in identifying the compound formed.

Five T-3G-1 Work Groups to Report at Northeast Region

Thirty members and guests attended the meeting of Task Group T-3G-1 (Cathodic Protection of Hull Bottoms of Ships) held at Dallas during the NACE Annual Conference.

Investigations will be continued by five work groups appointed last year at Baltimore so that formal reports can be made at the T-3G-1 meeting scheduled for the Northeast Region Conference October 11-14 in Huntington, W. Va.

The five work groups with their chairmen are as follows: (1) Cathodic Protection of the Stern Areas of Hulls: Charles F. Schrieber, Dow Chemical Co., Lake Jackson, Texas. (2) Shafts and Propellers: Charles F. Schrieber. (3) Types of Reference Electrode, Their Positioning and Interpretation of Potential Readings: Sidney Tudor, Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y. (4) Materials Available for Use as Anodes: T. J. Lennox, American Smelting & Refining Co., South Plainfield, N. J. (5) Shielding Required for Impressed Current and Galvanic Anode Systems: Leon Sudrabin, Electro Rust-Proofing Corp., Newark, N. J.

Backensto

Caldwell

Coburn

Foley

Godard

Maitland

Cathodic Protection for Stress Corrosion Discussed

Possible use of impressed current-anodic protection for control of stress corrosion cracking was discussed at the Dallas meeting of Technical Unit Committee T-5E (Stress Corrosion Cracking of Austenitic Stainless Steels).

Other problems discussed included importance of the nature of the oxide film on stainless and its modification as determined by electromicrographic studies, the role of oxygen and oxidizing-type water inhibitors in stress corrosion cracking and the susceptibility of precipitation hardened stainless steels to stress corrosion cracking.

•

NACE's 17th Annual Conference and 1961 Corrosion Show will be March 13-17, 1961, at the Hotel Statler in Buffalo, New York.

Godard Is Appointed Member of NACE Research Committee

Hugh P. Godard, immediate past president of NACE has been appointed a member of the NACE Research Committee. Chairman of this committee is A. H. Roebuck of the Western Company, Fort Worth, Texas.

Other committee members are J. A. Caldwell of Humble Oil & Refining Co., Houston, Texas, S. K. Coburn of U. S. Steel Corp., Monroeville, Pa., E. B. Backensto of Socony Mobil Oil Co., Inc., Paulsboro, N. J., and R. T. Foley of General Electric Co., Schenectady, N. Y. T. J. Maitland of American Telephone and Telegraph Co., New York, N. Y., is an ex officio member.

Roebuck

At its meeting durthe Dallas Conference, the committee discussed plans to submit suggested areas in which corrosion control research is needed. After further discussion and analysis, these suggested areas will be submitted for publication in CORROSION Magazine.

•

NACE Certificates of Membership are available from the Central Office. Measuring 5½ x 8½ inches, the certificates cost $2 each and are signed by the association president and executive secretary.

•

The American public buys about $85 billion worth of food a year, including about $200 million worth of gourmet delicacies.

Nace Technical Reports

STRESS CORROSION CRACKING. 15 papers reprinted from Corrosion. Pub. 59-4. Postpaid, per copy $3

HIGH PURITY WATER CORROSION. Sixteen papers reprinted from Corrosion. Pub. 59-3. Postpaid, per copy..... $3

1957-58 NACE TECHNICAL REPORTS. 38 reports reprinted from Corrosion. Includes some in Pub. 59-2 and 3 above. Postpaid, per copy. $6.50

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65¢ per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

2 TOUGH PIPELINE PROTECTORS

RUBEROID

ASBESTOS PIPELINE FELT...

Adheres to the pipe coating or enamel. Protects pipeline against root attack, soil distortion, and trench settlement which can occur from undergrowth in clay or rocky areas or where the soil is alternately wet and dry. Economical and long-lasting Ruberoid Pipeline Felt meets and exceeds the specifications of the American Waterworks Association and the National Association of Corrosion Engineers.

RUBEROID

FLEXIBLE ROCK SHIELD...

A durable pipeline protector. Guards pipelines in rocky and swampy areas, and at river, railroad and highway crossings. Also used to make tough saddle pads for river weights or hold-down anchors. Can be applied either in two pieces or by the cigarette wrap method. ½" or ¾" steel strapping with aluminum seals or use of filament tapes insures permanent placement of the shield. Saves time and effort. Light weight cuts freight cost.

For specification details and samples, write The RUBEROID Co., Industrial Products Division, 500 Fifth Ave., New York 36, N. Y.

The RUBEROID Co.®

PIPELINE PROTECTIVE COVERINGS THAT LAST

Committee T-4A Elects Mercer as Vice Chairman

C. L. Mercer of Southwestern Bell Telephone, Houston, Texas, has been elected vice chairman of Technical Unit Committee T-4A (Effects of Electrical Grounding on Corrosion). He has been with Southwestern Bell since 1933 and has been working on corrosion problems in the division since 1933.

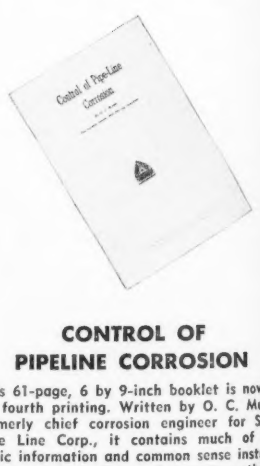
One of the first members of NACE during its organization, he has been active in the association, serving as technical committee officer and as co-chairman of the Utilities Industry Symposium for the 15th Annual NACE Conference in Chicago. He received his college education at the University of Tulsa and Rice Institute.

Mercer

T-8B Chairman Is Elected

W. G. Welter of General Petroleum Company, Whittier, Cal., has been elected chairman of Unit Committee T-8B (Refinery Industry Corrosion, Los Angeles Area).

E. B. Marquand of Aluminum Company of America, Los Angeles, Cal., is the new vice chairman; Cecil Cooper of Standard Oil of California, El Segundo, is secretary.



CONTROL OF PIPELINE CORROSION

This 61-page, 6 by 9-inch booklet is now in its fourth printing. Written by O. C. Mudd, formerly chief corrosion engineer for Shell Pipe Line Corp., it contains much of the basic information and common sense instruction needed to plan and execute cathodic protection systems on underground plant.

Per Copy, postpaid.....$1.25

5 or more copies, each.....$1.00

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas

NACE NEWS

Six Regional Conferences Scheduled This Fall

Technical Programs To Cover Variety of Corrosion Problems

Six NACE regional conferences will be held this fall during October and November. Corrosion problems of interest to industry in each of the regions will be discussed in technical papers presented at the conferences and in technical committee meetings.

The diversity of corrosion problems to be discussed include subjects of interest to the chemical industry, oil and gas production, refineries, utilities and pipe lines. General corrosion control methods such as protective coatings and cathodic protection also will be discussed.

Places and dates for the six regional conferences are given below.

Western Region

The Western Region will meet October 6-7 at the Sheraton-Palace Hotel in San Francisco, Cal. General conference chairman is G. J. Puckett of Dow Chemical Company. Advance program for the conference was published on Page 68 of June CORROSION.

A short course has been scheduled in conjunction with the Western Region Conference. It will be held October 3-5 in cooperation with the University of California at Berkeley and Los Angeles.

South Central Region

The South Central Region has scheduled its fall conference for October 25-27 at the May Hotel in Tulsa, Okla. General conference chairman is Richard Lembcke of Cities Service Research and Development Co., Tulsa.

North Central Region

October 19-20 has been set as the dates for the North Central Region Conference at the Pfister Hotel in Milwaukee, Wis. General conference chairman is Alexander McConnel of the George J. Meyer Manufacturing Company.

Northeast Region

The Northeast Region Conference will be held October 11-14 at the Prichard Hotel in Huntington, W. Va. General conference chairman is R. G. Schroeder of Standard Ultramarine and Color Company.

Southeast Region

Atlanta, Ga., will be the site of the Southeast Region's 1960 Conference. Meetings will be held at the Dinkler-Plaza Hotel on October 6-8. General conference chairman is H. T. Rudolph of Atlantic Coatings Co., Inc. An advance program of this conference was published on Page 62 of the June CORROSION.

Canadian Region

The Eastern Division of the Canadian Region has scheduled its conference for November 14-16 at the Sheraton Mount Royal Hotel in Montreal, Quebec.

Short Courses Scheduled

In addition to the short course to be held in conjunction with the Western Region Conference, two other short courses co-sponsored by NACE are scheduled for this fall.

A short course on process industry corrosion will be held September 12-16 at Ohio State University. The course will be presented by the university's Department of Metallurgical Engineering in cooperation with NACE's Technical Group Committee T-5 on Corrosion Problems in the Process Industries.

Another short course is scheduled for September 28-30 at the University of Oklahoma.

E. P. Noppel Retires After Forty Years in Corrosion

E. P. Noppel has retired recently from his position with Ebasco Services Inc., New York City, after over 40 years of work in the corrosion control field. One of the first members of NACE back in 1944, he has been active in NACE, serving at one time as chairman of the Regional Planning and Policy Committee.

After graduating from the University of Pennsylvania in 1914, he began his professional career as an engineer in charge of rail bonding and electrolysis work with the Scranton Railway Co., Scranton, Pa. Before joining Ebasco, he worked with American Electric Power Company of Philadelphia and Electric Bond and Share Company.

Noppel

His home address is 88 Gordonhurst Ave., Upper Montclair, N. J.

SECTION CALENDAR

July

6 Teche Section. Petroleum Club.

August

2 Shreveport Section. Ladies Night
3 Teche Section. Petroleum Club
9 Houston Section. To be at Houston Engineers' Club.

Canadian Region

Edmonton Section heard V. P. Milo of Shell Oil Company of Canada Limited, Calgary, present a paper on recent development on sulfide corrosion control at the May 26 meeting. An afternoon field trip also was held to the pipe coating yard of Northwestern Utilities Limited.

Recent Committee Appointments

Policy and Planning Committee

M. G. Fontana of Ohio State University and C. G. Munger of Amercoat Corp., South Gate, Cal., have been appointed for three-year terms to the Policy and Planning Committee. Mr. Fontana will represent the North Central Region; Mr. Munger, the Western Region.

Other members of the committee are Chairman R. A. Brannon, R. B. Hoxeng (Northeast Region), T. F. P. Kelly (South Central Region), A. R. Murdison (Canadian Region) and Miss I. M. Parker (Southeast Region).

Education Committee

Harry J. Keeling, consulting engineer of Los Angeles, Cal., has been appointed to the NACE Education Committee. Chairman of this committee is Norman Hackerman of the University of Texas, Austin.

Other members of the committee are Frank B. Burns, Mars G. Fontana, Edward C. Greco, Julius J. Harwood and Raymond B. Hoxeng.

Publications Committee

C. G. Munger of Amercoat Corporation, South Gate, Cal., recently was appointed to the NACE Publications Committee to serve as chairman of the Finance Subcommittee. R. S. Treseder is chairman of the Publications Committee.

Other members of the committee are J. L. Battle (Liaison with Technical Practices Committee), J. E. Loeffler (chairman of Advertising Subcommittee), R. D. Misch (chairman of Abstracts Subcommittee) and F. M. Reinhart (chairman of Review Subcommittee).

Ex officio members are T. J. Hull, NACE Executive Secretary, N. E. Hamner, Managing Editor of CORROSION, and Miss I. M. Parker, Editor of CORROSION.

Regional Management Committee

William F. Fair, Jr., of Koppers Company, Inc., Verona, Pa., has been appointed to the Regional Management Committee.

1960 Fifth Annual
Appalachian Underground Corrosion Short Course

Appalachian Short Course Has Record Breaking Enrollment

A record breaking attendance of 600 registrants was counted at the Fifth Annual Appalachian Underground Corrosion Short Course held June 1-3 at the university of West Virginia, Morgantown. Last year's enrollment was 535. Three foreign countries were represented: Mexico, Canada and Cuba.

Covering most all phases of underground corrosion, the short course was planned on three levels (basic intermediate and advanced) so that any person whose work may require a practical knowledge of underground corrosion could obtain useful information.

The course included classes on the practical and theoretical aspects of the causes of corrosion, instrumentation, corrosion surveys, cathodic protection, pipe coatings and miscellaneous methods of corrosion control.

The short course is sponsored by West Virginia University and is endorsed by NACE and the American Water Works Association.

1961 Committee Chairmen

NACE will be well represented by the committee chairmen (shown below) for the 1961 short course to be held June 6-8 at Morgantown. NACE member D. A. Tefankjian of Texas Eastern Transmission Co., Shreveport, La., will be general chairman. Other NACE members on the general committee are E. K. Bensen (program committee) of New York Telephone Co., Buffalo, N. Y., G. G. Campbell (exhibits committee) of West Virginia University, and John H. Alm (publicity) of Dearborn Chemical Co., Pittsburgh, Pa. R. E. Hanna, Jr., of West Virginia University will be in charge of registration.

This committee will hold a planning session in December at Pittsburgh, Pa., in conjunction with the NACE Pittsburgh Section meeting.

1961 APPALACHIAN SHORT COURSE CHAIRMEN selected last month at the fifth annual session of the short course are (left to right) R. E. Hanna, Jr., of West Virginia University (registration); NACE member E. K. Bensen of New York Telephone Co., Buffalo, N. Y. (program committee); NACE member D. A. Tefankjian of Texas Eastern Transmission Co., Shreveport, La. (general chairman); NACE member G. G. Campbell of West Virginia University (exhibits committee) and NACE member John H. Alm of Dearborn Chemical Co., Pittsburgh, Pa. (publicity committee).

APPALACHIAN SNAPSHOTS—(1) Largest classes of the short course were the ones on basic principles of corrosion. Part of the estimated 300 who attended these basic classes are shown here. (2) Checking the class schedule during a short break are three men with General Telephone Company of Pennsylvania: Ernest W. Traut of Youngstown, Ray P. Poorman of Erie, and H. W. Shaner. (3) Time was allowed for registrants to visit the many exhibits of corrosion control products and services. (4) After the class on cathodic protection theory conducted by NACE member W. J. Kretschmer and John H. Fitzgerald of Columbia Gas System Service Corp., class members examined the demonstration equipment used and asked questions of the two instructors. (5) John H. Fitzgerald and Arthur G. McPherson of Adams Pipe Repair Products, Columbia, Pa., examine the mud tub used by C. A. Erickson in his class demonstration. (6) An outdoor demonstration of pipe wrapping and coating equipment was given on the university drill field. A practical demonstration of measuring pipe potentials also was made on a pipe buried in the drill field three years ago. (7) NACE members A. F. Minor (chairman of NACE Northeast Region) and T. J. Maitland (current chairman of NACE Technical Practices Committee) of American Telephone & Telegraph, New York City, visited during the lunch period in the university field house. (8) After his mud tub demonstration, C. A. Erickson, Jr., of Peoples Natural Gas Co., Pittsburgh, Pa., answered questions from the students. He is one of the founders and the first chairman of NACE Group Committee T-7 on corrosion coordinating. (9) Five men from Texas Eastern Transmission Company check the schedule for their next class. Left to right they are David B. Wyatt of Chambersburg, Pa., R. H. Patterson of Somerset, Ohio, Robert E. Turpin of Woodsfield, Ohio, Arthur B. Stewart, Jr., of Seymour, Ind., and G. S. Jones of Shreveport, La. (10) Breaks between classes usually were continued discussions of material covered in class and renewals of old acquaintances.

NATIONAL and REGIONAL MEETINGS and SHORT COURSES

1960

Oct. 6-7—10th Annual Western Region Conference, Sheraton-Palace Hotel, San Francisco, Cal.

Oct. 6-8—Southeast Region Conference, Dinkler-Plaza Hotel, Atlanta, Ga.

Oct. 11-14—Northeast Region Conference. Prichard Hotel, Huntington, W. Va.

Oct. 19-20—North Central Region Conference. Pfister Hotel, Milwaukee.

Oct. 25-27—South Central Region Conference. Mayo Hotel, Tulsa.

November 14-16—Eastern Division, Canadian Region Conference, Hotel Royal, Montreal.

November 17-18—NACE Board of Directors Meeting, Sherman Hotel, Chicago, Ill.

1961

March 12—NACE Board of Director's Meeting, Hotel Statler, Buffalo, N. Y.

March 13-17—17th Annual Conference and 1961 Corrosion Show, Buffalo, N. Y., Hotel Statler.

March 17—NACE Board of Director's Meeting, Hotel Statler, Buffalo, N. Y.

Oct. 4-6—Western Region Conference, Hotel Multnomah, Portland, Oregon.

Oct. 9-11—North Central Region Conference, St. Louis, Chase Park Plaza Hotel.

Oct. 24-27—South Central Region Conference and Exhibition, Shamrock-Hilton Hotel, Houston.

Oct. 30-Nov. 2—Northeast Region Conference, New York City, Hotel Statler.

Southeast Region Conference, Miami, Fla., in conjunction with Miami Section's short course.

1962

March 19-23—18th Annual Conference and 1962 Corrosion Show. Kansas City, Municipal Auditorium.

October 1-4—Northeast Region Conference, Hotel Sheraton Ten Eyck, Albany, N. Y.

October 9-11—North Central Region Conference.

October 16-19—South Central Region Conference and Exhibition, Hilton Hotel, San Antonio.

SHORT COURSES

1960

September 12-16—Short Course on Process Industry Corrosion, sponsored by NACE Technical Committee T-5 and Ohio State University, to be held at Ohio State University, Columbus.

September 28-30—Central Oklahoma Section 1960 Corrosion Control Short Course, at University of Oklahoma, Norman.

October 3-5—Corrosion Control Short Course, sponsored by Western Region and University of California, San Francisco.

October 12-13—San Joaquin Valley Section Biannual Corrosion Tour Registration at Bakersfield Inn, Bakersfield, Calif.

November 7-11—Annual Florida General Conference Corrosion Short Course, Key Biscayne Hotel, Miami. Sponsored by Miami and Jacksonville Sections.

South Central Region

Six Symposia Listed on Advance Program For October 25-27 Tulsa Conference

Six symposia have been scheduled for the South Central Region Conference technical program to be held October 25-27 at the Mayo Hotel, Tulsa, Okla. The symposia will cover corrosion problems in water handling, chemical processing and refining, oil and gas pipelines, protective coatings and plastics, corrosion surveys and testing, and oil and gas production.

Technical papers scheduled at this time are given below by symposium.

Water Handling

"Inhibition of Mineral Scales" by L. W. Jones, Pan American Petroleum Corp., Research Dept., Tulsa, Okla.

"Comparative Laboratory Evaluation of Rapid Corrosion Inhibitor Screening Test" by J. Wade Watkins and J. Costangno.

Chemical Processing and Refining

"New On-Stream Corrosion Inspection Technique" by M. A. Meyn.

"Secondary Acetylenic Alcohols as Inhibitors of Acid Corrosion."

"Application of Cathodic Protection in the Oleum Refinery" by G. E. Moller and J. W. Caldwell.

"Zinc Based Organic Coatings for Protection of Refining Equipment" by J. B. Cox, Humble Oil & Refining.

"Anodic Protection Against H_2SO_4 Corrosion."

Oil and Gas Pipelines

"Economics of Deep Ground Beds" by F. A. Therrell, Interstate Oil Pipe Line, Shreveport, La.

Other papers to be scheduled.

Protective Coatings and Plastics

"Glass Reinforced Plastic Pipe and Tubing in Chemical Service" by D. D. Kays, Frontier Chemical Co., Wichita, Kan.

"Formulation and Application of a Bitumen Epoxy Coating for Pipelines" by J. James, Allied Paint, Tulsa, Okla.

Paper by Allen Thomas, Sunray Mid-Continent, Tulsa, to be scheduled.

"Economy in Airless Spraying Vinyls" by Dwight L. Du Puy, Union Carbide Chemicals, Texas City, Texas.

Additional papers for these symposia and on corrosion surveys and oil and gas production will be scheduled later. Additions to the technical program are scheduled for publication in the August issue of CORROSION.

•

Alamo Section heard Joe Gibson of the D. W. Haering Co., San Antonio, speak on microbiological acceleration of corrosion at the May 17 meeting.

•

Houston Section held a panel discussion on recent developments in the theory, testing and application of organic corrosion inhibitors for the June 14 meeting. Panel members were William B. Hughes, Tretolite Co., St. Louis, Mo., E. J. Simmons, Sun Oil Co., Dallas, and Jack P. Stanton, Visco Products Co., Houston. A. C. Nestle of Texaco, Inc., Houston, was panel moderator.

Next meeting is scheduled for August 9 at the Houston Engineers' Club.

•

Greater Baton Rouge Area Section had Joseph E. Harkins of Carpenter Steel Company as speaker for the May 23 meeting. He spoke on specifications of welded stainless steel tubing versus seamless stainless steel tubing. A film titled "Forming for Uniformity" was shown before the speech.

•

Sabine-Neches Section had J. P. Voorhies of Pfaudler-Permutit speak on glassed steel for the process industries at the May 26 meeting. His talk was illustrated with color slides. Next regular meeting will be in September.

•

Panhandle Section officers recently elected to take office at the September 27 meeting are as follows: Chairman J. R. St. Clair of White Deer, Texas, Vice Chairman Jack L. Carter of Hooker, Okla., and Secretary-Treasurer T. T. Harris of Phillips, Texas.

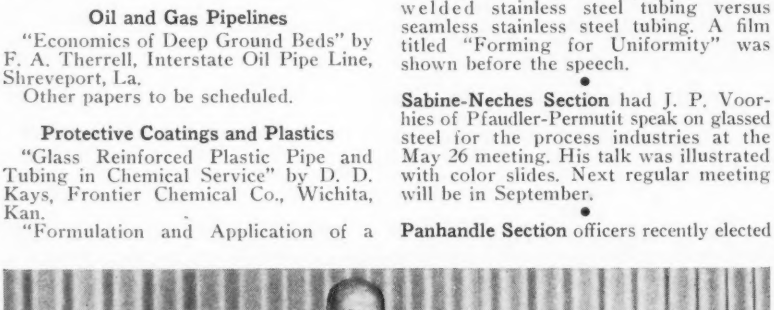
•

Central Oklahoma Section had John Sudbury of Continental Oil Company speak on oxygen corrosion of steel in the petroleum industry at the May 9 meeting.

A corrosion coordinating committee for western Oklahoma has been formed to discuss interference problems in cathodic protection. George Evans of Bell Telephone Company and Elmer Curry of Cities Service are co-chairmen.

•

East Texas Section heard R. L. Liggitt of Dia Log Company speak on tubing calipers for profile corrosion studies at the May 24 meeting.



TULSA SECTION honored five Tulsa high school seniors at the section's May 23 meeting. The five seniors were honored for their interest in science and for their exhibits in the recent Tulsa County Science Fair. Left to right they are Elvin Farrell, James O. Karn, H. H. Bliss (director of Oklahoma Science Service at Norman) Robert R. Lasecki, Michael Phillips and James F. Neal. A $100 contribution from the section was presented to Mr. Bliss for development of a science film library at the University of Oklahoma. The students' high schools and exhibit subject are as follows: Elvin Farrell, Nathan Hale High School, flow analyzer; James O. Karn, Central High School, use and experimentation of photovoltaic cells; Robert R. Lasecki, Will Rogers High School, narrow band cathode ray facsimile unit; James F. Neal, McLain High School, IGY objective and results; and Michael Phillips, East Central High School, infrared radar system.

Southeast Region

1960 Florida Short Course to Be Held Nov. 7-11 in Miami

The annual Florida General Conference Corrosion Short Course will be held November 7-11 at the Key Biscayne Hotel, Miami. The short course is sponsored by the Miami and Jacksonville Sections.

Tentative schedule for the course is as follows: Monday, November 7: registration and opening address. Tuesday, November 8: cathodic protection and coatings. Wednesday and Thursday, November 9-10: dual sessions on cathodic protection and coatings.

Other activities include a banquet to be held Thursday evening, November 10, and a round table discussion on Friday morning, November 11.

Some of the speakers and their topics scheduled at this time are given below: Solon Walker of East Tennessee Natural Gas Co., "Corrosion and Management." T. P. May of International Nickel Co., Inc., "Galvanic Corrosion." A. L. Ayres of New Jersey Bell Telephone Co., "Instruments and Testing Equipment." E. H. Phelps of U. S. Steel Corp., "Stress Corrosion of Steels for Aircraft and Missiles." H. T. Rudolph of Atlantic Coatings Co., "Surface Preparation for Coatings." D. R. Meserve of Metal & Thermit Corp., "Vinyl Coating Applications." Tom Bostwick, City of Jacksonville, "Condenser Tube Protection." Chris Georges of Pipe Line Services, "Application of Coating for Pipe." J. W. Cushing of Carboline Company, "Coating Comparison." F. C. Weber of Phelan-Faust Paint Mfg. Co., "Urethane Coatings." M. Frank and J. Whitley of Tennessee Gas Transmission Co., "Corrosion Survey Procedure."

Program chairman for the conference short course is C. H. Montague of Peoples Gas System Inc., North Miami.

•

Birmingham Section has Bill Miller of Southern Bell Telephone scheduled for a talk at the next section meeting on September 9. His subject will be "Communication and Air Defense."

James R. Anderson of Industrial Paint Mfg. Co., spoke on above ground corrosion at the May 6 meeting.

Western Region

San Francisco Conference Has Changes Made in October 6-7 Technical Program

Late changes in the technical program have been made for the 1960 Western Region Conference to be held October 6-7 at the Sheraton-Palace Hotel in San Francisco, Cal. Changes and additions given below are made on the tentative program published on Page 68 of the June issue of CORROSION.

A short course in corrosion control will be held in conjunction with the conference on October 3-5. (See Page 68 of the June issue.)

A paper entitled "High Temperature Corrosion Problems in the Petroleum Industry" by G. R. Prescott and R. B. Setterland of C. F. Braun & Co., Alhambra, Cal., has been scheduled for the Petroleum Processing Symposium. This symposium is scheduled for Thursday afternoon, October 6.

Dannier Emanuelson will be a co-author with E. H. Ehmke of Tidewater Oil Company on the paper "Service Experiences of a Fired Heater in a Catalytic Desulfurizer."

Robert L. Davis of Superior Oil Co., South Pasadena, Cal., will present a paper titled "Continuous Recording of Pipe-to-Soil Potentials versus Distance." This replaces the paper by Lindsay M. Applegate.

A title has been changed and a paper added for the Water Treatment and Inhibition Symposium scheduled for Friday afternoon, October 7. E. F. Duffek of Stanford Research Institute, Menlo Park, Cal., has changed his paper title to "Use of Inorganic Inhibitors for Corrosion Control in Water Treatment Systems." Werner Stumm of Harvard University, Cambridge, Mass., will present a paper on "Quantitative Evaluation of Corrosion in Water Supply Distribution Systems" in place of the paper by D. R. Boies.

A third paper has been scheduled for the Chemical Industries Symposium: "Stress Corrosion Cracking in Nitrate Fertilizer Solutions" by E. H. Edwards and R. L. Piehl, Standard Oil Company of California, and A. E. Barta of California Spray-Chemical Corp., Richmond, Cal.

•

Central Arizona Section elected the following officers for 1960: Chairman Blair B. Emory of Salt River Power District, Phoenix, Ariz., Secretary-Treasurer Richard Patterson of El Paso Natural Gas Co., Phoenix, Program Chairman Leonard F. Goodgame of Glendale, Ariz., and Membership Chairman George Menzler of Arizona Public Service Co., Phoenix.

•

San Francisco Bay Area Section had Troy J. McCormick of McCormick's Chemical and Inspection Company speak on chemical cleaning at the May 10 meeting.

•

Portland Section heard C. S. Miller of Hercules Powder Co., Wilmington, Del., describe physical properties, application methods and cost comparisons of Penton at the May 12 meeting.

•

Los Angeles Section held a panel discussion on interference problems of oil well casings in or near cathodically protected oil wells at the May 18 meeting. Panel members were Fred Small, Bryant Bradley and Robert Davis.

Seagren Appointed to ISCC

G. W. Seagren of Stoner-Mudge Co., Pittsburgh 33, Pa., has been re-appointed as NACE delegate to the Inter-Society Corrosion Committee for 1960-61. The other ISCC delegate from NACE is T. J. Maitland of American Telephone and Telegraph Co., New York, N. Y.

DEATHS

Stephen D. Day, founder and owner of the S. D. Day Company of Houston, Texas, died June 3. An NACE member since 1944, he had been in pipeline coating sales and supervision work with Pipe Line Service Corp., Houston, for 15 years before forming his own company in 1949 to handle pipeline coatings and wrappings. He served as a member of the NACE Board of Directors and was active in other NACE affairs.

RECTIFIER AND STACK FULLY

GUARANTEED* for One Year

Good-All

"PROTECTO-STACK"

Silicon

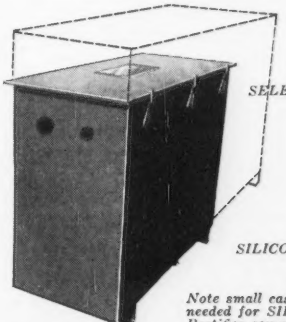
CATHODIC PROTECTION RECTIFIERS

Now for the first time—SILICON RECTIFIERS are GUARANTEED and proved in the field!

The entire Good-All Silicon Line now includes the latest Protecto-Stack features and circuitry which has proved reliable for over two years, under the severest operating conditions.

Protecto-Stack Features

- 1 phase center tap, 3 phase wye circuits fully utilize the silicon diodes for maximum efficiency.
- 1 phase bridge and 3 phase bridge circuits are also fully protected and guaranteed.
- The efficiency—compactness—non-aging simplicity of silicon.
- Smaller size and less weight—especially on large units and oil cooled units.



Note small case size needed for SILICON Rectifier compared to SELENIUM.

*See your representative. Write Good-All for Bulletin #9-C.

GOOD-ALL ELECTRIC MFG. CO. OGALLALA, NEBRASKA

A SUBSIDIARY OF THOMPSON RAMO WOOLDRIDGE INC.

Foreign Corrosion Reports

Foreign corrosion study reports for 1959 from India, Italy and France have been prepared by the Inter-Society Corrosion Committee's Subcommittee on Relations with Foreign Organizations. Hugh P. Godard, immediate past president of NACE, is chairman of this ISCC subcommittee.

Corrosion Activity in India

Activity in India in the field of corrosion increased in 1959 over the previous year. The most active research centers were the Electrochemistry Laboratory of the Indian Institute of Science at Bangalore and the Central Electrochemical Research Institute at Karaikudi.

The India Section of the (American) Electrochemical Society devoted considerable attention to corrosion by way of lectures, symposia and publication of technical papers. A new Indian journal "Electroplating" which covers metal finishing and corrosion was started during the year in Bombay.

The Ministry of Defense arranged a symposium on the conservation of materials at Kanpur in February. In November and December a refresher course on corrosion and its prevention was held at Karaikudi.

At Bangalore, Mr. Rama Char and co-workers have been studying the corrosion behavior of different aluminum alloys and its inhibition in alkaline and acid solutions. The anodic corrosion of several metals in pyrophosphate and sulphamate plating solutions was studied also. At Karaikudi, Rajagopalan and coworkers are studying corrosion in unpolluted atmospheres, vapor phase inhibitors, the effect of pre-treatment on corrosion and the inhibition of steel corrosion. Other work is being done in India on corrosion in synthetic atmospheres, underground corrosion and protection of steel by paints.

During the year, 27 papers on plating and corrosion were published in Indian and foreign journals.

T. L. Rama Char
Indian Institute of Science
Bangalore 12, India

Corrosion Activity in Italy

In the Electrochemical, Physical Chemical and Metallurgical Laboratories at the Politecnico di Milano, systematic research on the electrochemical behavior of metallic single crystals (grown by a modified Bridgman method) has been continued. The anodic and cathodic overvoltages and the hydrogen overvoltage have been investigated on oriented single crystal electrodes of Pb, Sn, Cd, Ag, Cu, Ni, Bi, Sb and Zn. A monograph titled "Electrochemistry of Single Crystals" is being prepared.

R. Piontelli has just published a book in Italian with the title "Elementi di teoria della corrosione a umido dei materiali metallici" (Elements of the theory of corrosion of metals under humid conditions) published by Longanesi of Milan.

Systematic research on inhibitors has been carried out in the Chemical Laboratory of the University of Ferrara.

Professor G. Bianchi is now in charge of the Chemical Department of the University of Milan and is doing corrosion research.

Corrosion investigations on various topics have been carried out in the research laboratories of different industries.

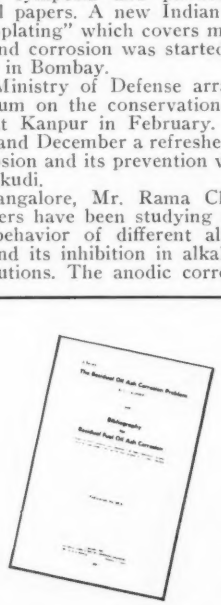
R. Piontelli
Laboratori di Elettrochimica
Politecnico di Milano
Piazza Leonardo da Vinci, 32
Milano, Italy

Corrosion Activities in France

During 1959, the principal researches carried out in France dealt with the following points:

1. Chemical properties of high purity metals. This work is being done mainly in Les Laboratoires de Vitry du Centre Nationale de la Recherche Scientifique.
2. Mechanism of oxidation of iron and copper at elevated temperature by Professor Benard at the Sorbonne. Results of this work were presented at a recent conference in Munich.
3. Fixation of sulfur on mono and polycrystalline iron by Professor Lacombe.
4. Corrosion testing of different metals

(Continued on Page 71)



Residual Oil Ash Corrosion Problem and Bibliography for Residual Oil Ash Corrosion

A clearly written summary of this important corrosion reaction and what is being done to control it. The bibliography consists of 272 titles, 1919-1959 inclusive. Publication 60-6.

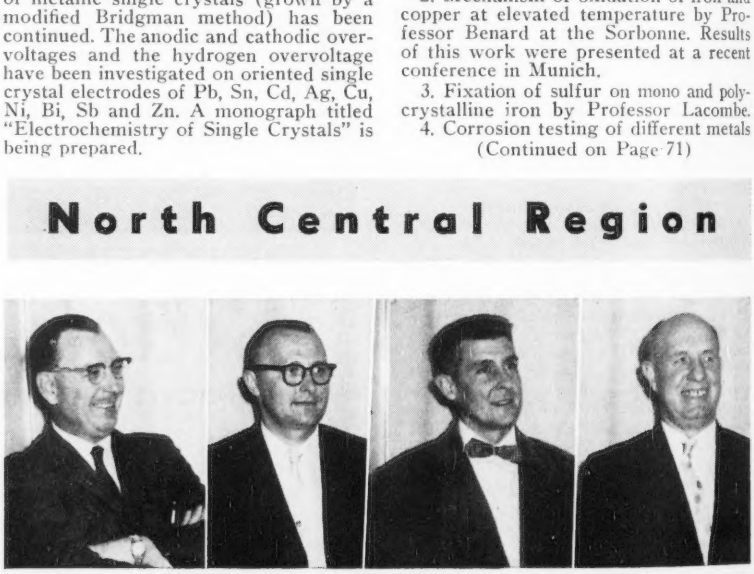
Per copy, postpaid

Non-members of NACE.....$2.50
NACE members.....$2.00
NACE Corporate Members.....$1.75
(Reduced prices on over 5 copies on request)

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

NATIONAL ASSOCIATION OF CORROSION ENGINEERS
1061 M & M Bldg. Houston 2, Texas

North Central Region



TWIN CITY SECTION OFFICERS recently elected are left to right: Chairman C. C. Van Rickley of McCord Maintenance Engineers, St. Paul; Secretary-Treasurer J. F. Williams of Northern States Power Co., Minneapolis; and two members to the governing board. They are W. Hill of Northern Natural Gas Co., Owatonna, and L. Adams of Minneapolis Water Department. The Twin City Section, recently organized, is NACE's 61st section.

October 19-20 Conference To Cover Four Industries

Corrosion problems related to four industries in the North Central United States will be discussed in technical symposia at the October 19-20 North Central Region Conference to be held at the Hotel Pfister in Milwaukee, Wis.

The symposia will be on utilities, process, brewing and pulp and paper industries.

Also scheduled for the conference are a luncheon, business meeting, special social activity and meetings of the NACE Technical Practices Committee.

Meetings have been scheduled for the Process Industry and Utility Symposia on Wednesday and Thursday mornings, October 19 and 20. The Brewing Industry Symposium will meet Wednesday afternoon; the Pulp and Paper Symposium on Thursday afternoon.

Inquiries on registration and hotel accommodations should be addressed to Tom Quick, Randolph Hotel, 649 North Fourth St., Milwaukee 1, Wis.

●

Southwestern Ohio Section heard William Jaques of Procter & Gamble speak on "Management Approach to Corrosion Engineering" at the May 31 meeting.

●

NACE Certificates of Membership are available from the Central Office. Measuring 5½ x 8½ inches, the certificates cost $2 each and are signed by the association president and executive secretary.

Foreign Corrosion—

(Continuel From Page 70)

in high temperature water by Dr. Herenguel.

5. Study of steels resistant to hydrogen sulfide by Dr. Herzog.

6. Corrosion of magnesium in humid air by Dr. Caillat at the French Atomic Energy Commission.

7. Corrosion of aluminum alloys in high temperature steam by Mr. Coriou.

8. Important information on electrolytic polishing and the hydrogen content of steel was presented by Messrs. Jacquet and Bastien respectively.

9. Marine corrosion of steels by M. Hache.

The report includes a list of 76 corrosion papers published in France during 1959 which is available on request.

G. Chaudron
University of Paris
Faculte des Sciences
11, Fue Pierre Curie
Paris 5e, France

NACE Directors Consider Metal Plaques for Awards

Presentation of metal plaques in lieu of the hand lettered certificates customarily given to persons receiving NACE Whitney and Speller awards is under consideration by the board of directors. A committee has been instructed to look into the proposal and make recommendations. The substitution of plaques for certificates presented to past presidents also is being considered.

•

The 1960 Southeast Region Conference will be held Oct. 6-8 at the Dinkler-Plaza Hotel, Atlanta, Ga.

Lapel Pins

Approx. Size

Approximately 7/16 inches high, gold, inlaid with bright red enamel background to "NACE" and deep blue enamel background to words "CORROSION CONTROL." Ruby center.

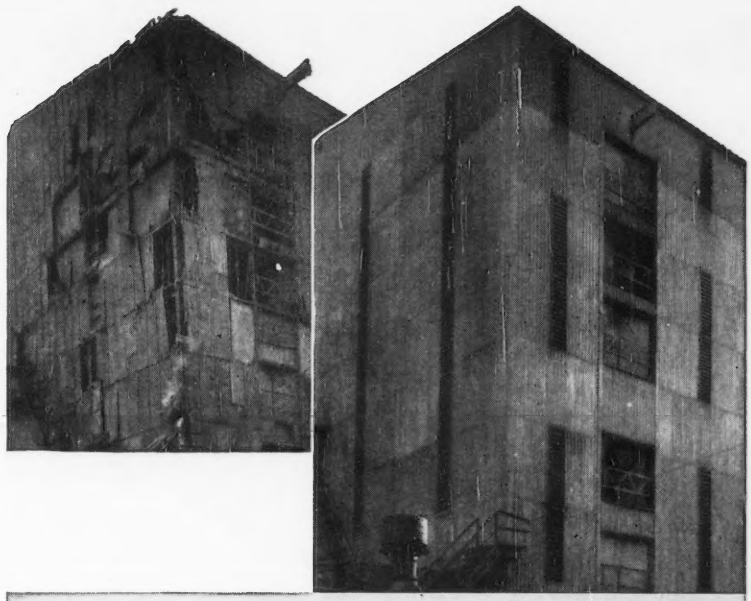
•

For Association Members Only

$10

Address Orders to
T. J. Hull, Executive Secretary

NATIONAL ASSOCIATION OF CORROSION ENGINEERS
1061 M & M Bldg., Houston 2, Texas



Acid Processing Fertilizer Plant Gets a New Maintenance-Free Skin of RESOLITE

It's hard to believe, but this fertilizer plant had deteriorated to the condition shown in the photograph at the left in a little over four years. The deterioration was caused mainly by the corrosive conditions which exist in such operations. RESOLITE engineered and furnished over 24,000 square feet of opaque "Fire-Snuf" formulation Metal Gray Panels for walls and roof area. The material was made in the V-beam shape, and is manufactured using a special formula designed for highly corrosive acid conditions. All louver assemblies, flashing and gravity roof ventilators were fabricated by RESOLITE. All fasteners are also corrosion-resistant and supplied by RESOLITE.

Here is an example of how RESOLITE engineers can be of service to you. We are specialists in engineering the use of reinforced polyester panels, and our years of experience can be of value to you. Write today for our 8-page folder on the use of RESOLITE panels and special shapes in applications where corrosion is a problem.

Engineering Specialists in Reinforced Polyester Panels

RESOLITE CORPORATION
P. O. BOX 539, ZELIENOPLE, PA.
DISTRIBUTORS IN PRINCIPAL CITIES

Northeast Region

Oct. 11-14 Huntington Conference Lists Eight Symposia on Technical Program

Tentative technical program for the 12th Annual Northeast Region Conference for October 11-14 lists eight symposia. The conference will be held at the Hotel Prichard in Huntington, W. Va. Tentative schedule of papers are listed below by symposium.

Wednesday, October 12
Protective Coatings for Atmospheric Exposure

Moderator will be Kenneth Tator of Kenneth Tator Associates, Coraopolis, Pa.

1. Owner's Part in Industrial Maintenance Painting, by T. F. Stanley of Monsanto Chemical Co., Monsanto, Ill.

2. Material Manufacturer's Part in Industrial Maintenance Painting, by C. G. Munger of Amercoat Corp., South Gate, Cal.

3. Painter's Part in Industrial Maintenance Painting, by Lowell S. Hartman of Hartman-Walsh Painting Co., St. Louis, Mo.

4. Round table discussion on maintenance painting problems.

Inhibitors

Papers to be scheduled at later date. Plant trips have been planned. Chairman of this symposium will be W. W. Sweet of Colgate Palmolive Co., Jersey City, N. J.

Thursday, October 13
Protective Coatings for Immersion Service

Moderator will be R. O. Jackson of Jackson Associates Sales, Hamilton, Ohio.

1. Pre-Shrunk Films—Those Remarkable Epoxies Again, by Richard G. Fortener of Jones-Dabney Co., Louisville, Ky.

2. Tonic Solvents—What You Should Know About Them, by E. G. Meiter of Employers Mutual Insurance Co., Wausau, Wis.

3. Paper by R. E. Robinson of Hooker Chemical Co., Niagara Falls, N. Y.

4. Paper by representative of Pfaudler Co., Rochester, N. Y.

High Temperature Corrosion

Papers to be scheduled at later date. Chairman is E. N. Skinner of International Nickel Co., Inc., New York, N. Y.

Fresh Water Corrosion

Chairman will be C. P. Dillon of Union Carbide Chemicals Co., Institute, W. Va.

1. Principles of Water Treatment, by Paul Bird of Wright Chemical Co., Chicago, Ill.

2. Recirculated Cooling System, by J. M. Brooke of Phillips Petroleum Co., Sweeny, Texas.

3. Materials of Construction for Natural Fresh Waters, by G. B. Elder of Union Carbide Chemicals Co., South Charleston, W. Va.

Plastics

Chairman will be W. A. Szymanski of Hooker Chemical Corp., Niagara Falls, N. Y.

1. New Design for Reinforced Plastic Tanks, by F. H. Humphrey, plastics consultant of Toronto, Ontario, and W. R. Wandrop of Metal Cladding, Inc., North Tonawanda, N. Y.

2. Plastics as Construction Materials in Industry, by J. Bigos of U. S. Steel Co., Monroeville, Pa.

3. Comparative Study of Corrosion Resistance of a Bisphenol Resin, Isophthalic Resin and a General Purpose Polyester Resin, by A. F. Torres and S. S. Feuer of Atlas Powder Co., Wilmington, Del.

4. Design of Glass-Reinforced Plastic Structures, by Lawrence Fischer of Grumman Aircraft Engineering Corp., Bethpage, N. Y.

Friday, October 14
Underground Corrosion

Chairman will be C. A. Erickson, Jr., of Peoples Natural Gas Co., Pittsburgh, Pa.

1. Plastic Pressure-Sensitive Tapes as Pipe Coating Materials, by George F. Roberts of Seamless Rubber Co., New Haven, Conn.

2. Insulating Joints, by George D. Kish of Dresser Manufacturing Division, Bradford, Pa.

3. Cathodic Protection of Well Casings, by W. R. Lambert of United Fuel Gas Co., Charleston, W. Va.

4. Maintenance Practices of Corrosion Control Facilities for Underground Structures, by D. A. Tefankjian of Texas Eastern Transmission Corp., Shreveport, La.

Chemical and Refinery Process Corrosion

Chairman will be W. H. Burton of Allied Chemical Corp., Camden, N. J.

1. Corrosion Characteristics and Uses of Glassed Steel, by David K. Priest of Pfaudler Co., Rochester, N. Y.

2. Corrosion of Weak Acids Under Heat Transfer Conditions, by N. D. Groves, C. M. Eisenbrown and L. R. Scharfstein of Carpenter Steel Corp., Reading, Pa.

3. Chloride Corrosion and Fouling in Catalytic Reformers and Naphtha Pretreaters, by E. B. Backensto and A. N. Yurick of Socony Mobile Oil Co., Paulsboro, N. J.

4. Paper by E. W. Kleefish of Nooter Corp., St. Louis, Mo.

5. Corrosion Resistance of Steels, by S. W. Shepard of Chemical Construction Corp., New York, N. Y.

•

Genesee Valley Section elected the following officers at the May 17 meeting: Chairman E. Grant Pike of the Dolinger Corp., Rochester; Vice Chairman Richard H. Saunders of Rochester Gas & Electric Corporation; Secretary-Treasurer Robert M. White of Eastman Kodak Co., Rochester.

G. M. Taylor of Hercules Powder Company will speak on Penton at the next meeting scheduled for October 25.

•

Niagara Frontier Section had an estimated 150 corrosion engineers and maintenance personnel attend its Coatings Symposium held May 11-13. Theme of the symposium was corrosion control in the chemical industries.

Metropolitan New York Section heard E. H. Thalmann of Ebasco Services, Inc., New York City, speak on underground pipe coatings at the May 11 meeting.

•

Kanawha Valley Section scheduled a talk by Charles M. Loucks of Cleveland, Ohio, for its May 26 meeting in Huntington, W. Va. His subject was "Chemical Cleaning of Process Equipment in Chemical, Gas and Utilities Field."

Technical Articles Published Since 1945 Available on Lists

All of the technical articles published in CORROSION since 1945 have been arranged by principal topics and published in a new reference document available on request from NACE. The publication is called "Technical Reprints and Books."

The document has been prepared in recognition of the long-time need for a list of all of the technical material available from NACE. It permits those interested in the more than 7000 pages of corrosion control information published in CORROSION, and in NACE's books and pamphlets, to order copies without delay or further correspondence. Prices of each article and book are given.

Arrangement is by adaptation of parts of the NACE Abstract Filing Index. Number coding permits location of the articles as to year of publication in CORROSION and the issue of publication. The pages are numbered so that the Technical Reprints and Books list may be supplemented internally from time to time with titles of newly-published articles and books without disturbing existing pagination.

Persons to whom the document is sent will be asked to keep it filed because it may be used indefinitely as a reference.

It does not supplant either the 10-Year Index to CORROSION or the 5-Year Index to CORROSION (1955-59) now in preparation. These are liberally cross-indexed and lead into the complete subject matter of the technical data available in CORROSION, whereas the Technical Reprints and Books List puts the article under one subject only.

NEW PHOTOCOPY PRICES

The following schedule of photocopy prices for NACE literature is now in effect:

Minimum charge	$1.00
3 pages or less, per page	.50
10 pages or less, per page	.35
11 pages or more, per page	.25

Ohio State Short Course Registration Fee to Be $65

Registration fee for the Short Course on Process Industry Corrosion to be held September 12-16 at Ohio State University will be $65. Enrollment will be limited to 150. Registrations accompanied with full fee should be mailed before August 26 to M. G. Fontana at Ohio State University. Checks should be made payable to Ohio State University.

CORROSION ABSTRACTS

INDEX TO CORROSION ABSTRACTS

Vol. 16 July, 1960 No. 7

2. TESTING
- 2.3 Laboratory Methods and Tests 73
- 2.4 Instrumentation 73

3. CHARACTERISTIC CORROSION PHENOMENA
- 3.6 Electrochemical Effects 74
- 3.7 Metallurgical Effects 74
- 3.8 Miscellaneous Principles 74

6. MATERIALS OF CONSTRUCTION
- 6.2 Ferrous Metals and Alloys 75
- 6.3 Non-Ferrous Metals and Alloys—Heavy 75

7. EQUIPMENT
- 7.5 Containers 77
- 7.6 Unit Process Equipment 77

8. INDUSTRIES
- 8.4 Group 4 77
- 8.6 Group 6 79
- 8.9 Group 9 79

2. TESTING

2.3 Laboratory Methods and Tests

2.3.5, 2.3.9

Methods of Determining Surface Roughness. M. K. Testerman. Univ. Fayetteville, Arkansas. U. S. Wright Air Development Center, Technical Rept. 58-230, June, 1958, 48 pp.

Twelve techniques for investigating the microscopic surface roughness of continuous surfaces are cited as background. (WADC TR 56-233 in a critique of known methods for measuring surface roughness.) Of these the method of capacitance measurements was chosen for experimental investigation. Measurements of permanent capacitance were made upon specimens coated with monomolecular films and were found not to be reproducible. Measurements of polarization capacitance made in aqueous electrolyte solutions were reproducible. Two methods of measuring polarization capacitance were tested namely, the charging curve method, and the bridge method for copper, nickel and steel surfaces. Investigations with formamide and acetonitrile revealed that these nonaqueous solvents were not satisfactory for polarization capacitance measurements. Experimentation was begun to establish a radioactive method for measuring surface roughness. Results were obtained that indicate this method to be better for aluminum surfaces than is the polarization capacitance method. (auth)—NSA. 18967

2.3.5, 4.6.2, 6.3.20

A Study of Corrosion Films on Zirconium and Its Alloys by Impedance Measurements. J. N. Wanklyn and D. R. Silvester. Atomic Energy Establishment, Harwell. J. Electrochem. Soc., **105,** No. 11, 647-654 (1958).

The oxide films formed on zirconium and some of its alloys during corrosion in steam and water at 325 C have been studied by impedance measurements made by immersion in an electrolyte. A fall in the protective character of the film is accompanied by an increase of capacity, and measurements of the latter provide a useful method of comparing films. The behavior of the resistive part of the impedance and the influence of frequency and electrolyte conductivity are complex, and only a partial interpretation can be given. 16674

2.3.6, 3.8.4, 6.3.14

Microstructure of Anodic Layers on Tin. Indra Sanghi. Current Sci., India, **26,** No. 6, 175-176 (1957).

An electron-microscope study was made of anodic films formed on tin (99.99 percent) by galvanostatic polarization of 0.1 normal sodium hydroxide. A series of active, passive and oscillating films was prepared by varying the current density and immersion time of successive tin strips. On removal from the bath, a film of nitro-cellulose was applied to support the anodic layers while the metal substrate was dissolved in mercury. The oxide was transferred to a Formvar-covered specimen grid and the nitro-cellulose removed. Micrographs are shown of 1) a basal-ground-layer of oxide which shows only the etch structure of the metal; 2) the formation of two distinct layers on a mechanical polished specimen; 3) the effect of anodizing time—at short times, fine markings appear which suggest possible shrinkage or folding of layers—at longer times, the films thicken and are seen to be porous.—MA. 16303

2.4 Instrumentation

2.4.2, 2.3.7, 3.2.2

Measurement of Intercrystalline Corrosion by the Method of Resonance Frequency. Karel Smrček. Werkstoffe u. Korrosion, **9,** No. 8/9, 550-552 (1958).

An apparatus is described for measuring the resonance frequency of small metal bars. The change of resonance frequency with time of exposure to intercrystalline corrodants provides graphical representation of this corrosion. The effect of heat-treatment upon intercrystalline corrosion is demonstrated by this method for brass and stainless steel.—MA. 18958

2.4.2, 2.3.6

Inexpensive Apparatus for Interferometrically Measuring Thickness of Electroplated Chromium and Other Thin Films. Roger L. Saur. Plating, **45,** No. 12, 1232-1233 (1958).

Interference fringes are used to measure the thickness of a stripped film, the edge of which must be bevelled in order to determine the fringe deviations across the edge. An electrolytic method for bevelling is described. The method can be adapted to measure transparent films, e.g. anodic aluminum films.—MA. 18938

2.4.2, 3.4.6

Pressure Gauge for Corrosive Gases in the Micron and Submicron Region. J. R. Anderson. Univ. of Melbourne. Rev. Sci. Instruments, **29,** 1073-1078 (1958) Dec.

A gage is described, for use with corrosive gases in the range of 10^{-2} to 10^{-5} mm mercury, in which the pressure is indicated by the rate of damping of a hinged silica fiber pendulum. Amplitude is measured photoelectrically. The gage exposes only glass and silica to the gas, may be baked to 450 C, and gives an accuracy of pressure measurement of better than 5 percent. (auth)—NSA. 18163

2.4.2, 8.4.5

Rating Heat Transfer Surface for Corrosion. N. D. Groves and C. M. Eisenbrown. Carpenter Steel Co. Metal Progress, **75,** No. 5, 78-81 (1959) May.

Test apparatus developed by N. D. Groves was used to predict life of heat transfer surfaces in atomic energy installations. Weight loss of a metal immersed in a corrosive solution can be accurately determined. Specimen and corrodent can be maintained at different temperatures simulating heat transfer conditions. Reaction vessel which holds corrodent is wound with a resistance heater to supply extra heat when required. Attached to bottom is a metal specimen heated externally by a 550-w. soldering iron. Thermocouple at mid-

Abstracts in This Section are selected from among those supplied to subscribers to the NACE Abstract Punch Card Service. Persons who are interested in reviewing all available abstracts should write to NACE for information on this service.

PHOTOPRINTS and/or MICROFILM COPIES

of Technical Articles Abstracted in

Corrosion Abstracts

May Be Obtained From

ENGINEERING SOCIETIES LIBRARY, 29 West 39th Street, New York 18, N. Y.

CARNEGIE LIBRARY OF PITTSBURGH, 4400 Forbes St., Pittsburgh 13, Pa.

NEW YORK PUBLIC LIBRARY, New York City.

U. S. DEPT. OF AGRICULTURE LIBRARY, Office of Librarian, Washington, D. C. (Special forms must be secured).

LIBRARY OF CONGRESS, Washington, D. C.

JOHN CRERAR LIBRARY, 86 East Randolph St., Chicago 1, Ill.

Persons who wish to secure copies of articles when original sources are unavailable, may apply directly to any of the above for copies. Full reference information should accompany request. The National Association of Corrosion Engineers offers no warranty of any nature concerning these sources, and publishes the names for information only.

NACE will NOT accept orders for photoprint or microfilm copies of material not published by the association.

point of specimen measures metal temperature, while another thermocouple in vessel determines solution temperature. Nichrome immersion heater is also used. This apparatus was used to investigate Carpenter Stainless No. 20-Cb as a heat transfer surface in sulfuric acid. Graphs illustrate relationship between metal temperature and corrosion rate at various acid concentrations and between acid concentration and corrosion rate at various temperatures. Typical example is given of how, by means of these curves, designers can control size of heat exchangers for sulfuric acid. Photo and diagram of apparatus.—INCO 18287

3. CHARACTERISTIC CORROSION PHENOMENA

3.6 Electrochemical Effects

3.6.5, 3.6.6, 6.2.2, 6.3.14

Electromotive Forces and Electrode Potentials of Tin and Iron in Systems with Tin Containing Flux Electrolytes. (In Russian.) A. L. Vitkin. Central Inst. of Ferrous Metallurgy, Moscow. J. Phys. Chem., U.S.S.R. (Zhur. Fiz. Khim.), **32,** 1612-1617 (1958).

Measurements show that in the galvanic cell tin/flux/iron, tin is the anode, whereas iron (plate) is the cathode on which tin from the electrolyte is deposited. Hence on close circuiting the cell the electrode potential difference is at its maximum value only for a fraction of a second, after which, owing to the shift of the cathodic potential to the negative, the emf falls. At high temperature the flux diffusion processes during the precipitation of the tin on the cathode are quite rapid, forming the intermetallic compounds $FeSn_2$ of a new crystal structure. Measurements of emf and electrode potentials of tin and iron in systems with tin containing electrolytes were carried out with respect to duration of the process and concentration of the tin chlorides. It was shown that in molten fluxes the process of tin deposition on the cathode is more rapid than when the flux is in the form of a solution. Measurements of the emf of the system $Zn/ZnCl_2/Fe$ characterize the work of the flux during thermal zinc plating. In this case the emf is considerably higher than in tin-iron galvanic pairs. (auth).—NSA. 17657

3.6.8, 3.8.3, 6.2.5, 4.3.2

Polarization Characteristics and Stability of Passive State of Stainless Steel. G. Okamoto, M. Nagyama, Y. Mitani and T. Ishikawa. Paper before Electrochem. Soc. Jap. 6th Corrosion Symposium, June, 1958. J. Electrochem. Soc. Japan, **27,** No. 6, 325-331 (1959) June.

Study was made on the three reactions, such as steel-dissolution, oxygen-reduction and hydrogen-evolution which take place when the surface of stainless steel is subjected to action of air-saturated dilute sulfuric acid, and from the results obtained the general conception concerning the effect of polarization on each of these reactions in connection with the stability of passive state of the metal is described. The most suitable method to obtain a polarization curve of each reaction is derived, based on the fact that the steel dissolution reaction is independent of the oxygen-reduction reaction. By measuring the polarization curve by means of constant potential analysis of austenitic stainless steels in a 5% sulfuric acid solution at 50 c containing two varieties of molybdenum content, it has been clarified that the oxygen-reduction reaction curve gives an almost similar limit current (50 μA/cm^2) in the range of active state potential and that increase in stability of passivity by an addition of molybdenum is mainly due to the suppression of steel-dissolution reaction. The dependence of temperature and stirring on the steel-dissolution and oxygen-reduction reactions at the potential of the maximum steel dissolving velocity for passivity was investigated and found that the former is controlled by the surface reaction process and the latter is controlled by the oxygen diffusion process.—INCO. 18493

3.7 Metallurgical Effects

3.7.2, 3.7.4, 6.4.2, 4.6.5

Aluminum Alloys Containing Iron and Nickel: Effect of Structure and Composition on the Resistance to Corrosion by Water at High Temperatures. (In French.) H. Coriou, L. Grall, J. Huré and A. Roux. Rev. Mét., **55,** No. 10, 953-967 (1958) October.

Corrosion structures of a range of aluminum alloys containing $\geq$ 3 percent iron plus nickel were determined after 5000 hr. in de-ionized water in an autoclave at 350 C. For contents $>$ 0.5 percent iron plus nickel the predominant factor is the distribution of the insoluble intermetallic compounds, which should be as fine and as evenly distributed as possible. The corrosion products on the surface are subdivided into three distinct layers whose total thickness rapidly approaches a limiting value.—MA. 18071

3.7.2, 3.7.4, 6.4.2, 4.6.5, 3.5.9

Effect of Silicon on the Resistance of Aluminum-Iron Alloys to Corrosion by Water at High Temperatures. (In French.) H. Coriou, L. Grall, A. Hauptmann and J. Huré. Rev. Mét., **55,** No. 10, 968-975 (1958) October.

A series of aluminum alloys containing iron 0.3-0.6 and silicon 0.06-0.4 percent were subjected to corrosion-tests in de-ionized water at 250-350 C. Corrosion-resistance is directly related to modifications of the alloys structure due to iron and silicon. In the iron 0.46, silicon 0.15 percent alloy after quenching, a single constituent, $FeAl_3$, is precipitated in a homogeneous solid solution; after annealing at 350 C, plates of $Al_{12}Fe_3Si$ appear, and after annealing at 450 C and slow cooling to 150 C, a new phase, $Al_9Fe_2Si_2$, appears. On the other hand, in the quenched iron 0.57, silicon 0.33 percent alloy, traces of $FeAl_3$ are enclosed in plates of Al_2Fe_3Si, and after annealing at 450 C and slow-cooling, the $Al_9Fe_2Si_2$ is much more abundant. The deleterious effect of the silicon is counterbalanced by the iron, which precipitates the silicon in the ternary compounds. The iron is also needed for the precipitation of the $FeAl_3$, necessary for good corrosion-resistance.—MA. 18072

3.7.3, 6.2.5

Corrosion of Stainless-Steel Welds Formed with Carbon-Dioxide Shielding, B. E. Hopkinson and D. M. McDowell. Paper before American Welding Society, 40th Annual Meeting, Chicago, April 6-10, 1959. Welding J., **38,** No. 4, 188s-193s (1959) April.

Compares effect on weld chemistry and corrosion resistance of stainless steel weldments made under carbon dioxide shielding, with similar welds made under argon plus 1 percent oxygen. Both single-pass and multi-pass type welds were fabricated and examined. It was found that although carbon content of chromium-nickel stainless steel weld metal increases when welding is carried out under carbon dioxide, corrosion resistance is impaired only in multi-pass weldments. Resistance to corrosion was evaluated by testing in boiling 65 percent nitric acid, and ferric sulfate-sulfuric acid solutions. In multi-pass welds the earlier passes are presumably sensitized by subsequent heating during later welding operations. Changes in chemical composition caused by welding under carbon dioxide are related to weld structure. Corrosion attack followed ferrite areas. Tables, micro- and electronmicrographs.—INCO. 18435

3.7.3, 8.9.3

Anti-Corrosion Measure. Insulated Flange Joints Preassembled and Tested. M. Buechler. Pipeline News, **31,** No. 5, 67-68, 70 (1959) May.

Pre-assembled and tested insulated flange joints for pipelines can be guaranteed for the maximum operating pressure, zero conductivity when measured by sensitive ohmmeters, proper gasket seating without injury to the gasket, and manufacture for particular surface conditions. 18320

3.7.4, 6.2.5

Corrosion Resistance of Stainless Steels. Pt. 10. The Sigma Phase. (In Italian.) Lars Morsing. l'Acciaio Inossidabile, **26,** 125-139 (1959) July-Aug.

Formation of sigma phase in ferritic, ferritic-austenitic, 18-8 austenitic and highly alloyed austenitic steels, and particularly in a number of Avesta steels. Influence of sigma phase on corrosion resistance and mechanical properties.—RML. 18442

3.7.4, 6.3.21, 4.3.7

A Study of the Chemical Attack and Oxidation of Oriented Surfaces of Germanium Single Crystals. (In French.) (Mme) Léone Gouskov and Nicolas Nifontoff. Compt. rend., **248,** No. 10, 1499-1502 (1959).

Different appearances of the (001), (110) and (111) faces after corrosion in hydrogen peroxide solution and after more or less severe oxidation are recorded.—MA. 18290

3.8 Miscellaneous Principles

3.8.2

Kinetic Studies on Corrosion Systems. Pt. I. Polyelectrodes under Activation Control. Franz A. Posey. Oak Ridge National Lab. J. Electrochem. Soc., **106.** No. 7, 571-581 (1959) July.

Electrochemical kinetics has been applied to the case of corroding polyelectrodes under activation control for the situation where the rates of partial processes vary over the surface of an electrode. Explicit expressions have been derived for rate and potential in the simplest polyelectrode systems. The kinetics of galvanic couples under activation control has been derived with emphasis on the significance of measurable quantities. The use of steady-state polarizability measurements, potentiostatic measurements and galvanostatic measurements in the study of polyelectrode systems has been outlined. 18495

3.8.2, 3.8.3

Kinetic Studies on Corrosion Systems. Pt. II. The Reduction of Cupric Ion on Passive Stainless Steel Electrodes. Franz A. Posey, G. H. Cartledge and R. P. Yaffe. Oak Ridge National Lab. J. Electrochem. Soc., **106,** 582-589 (1959) July.

Reduction of cupric ion on the surface of passive stainless steel electrodes in aerated, dilute sulfuric acid medium has been investigated using potentiostatic, galvanostatic and tracer techniques. The independent simultaneity of the electrode reactions has been demonstrated. A mechanism is advanced for the reduction of cupric ion on the oxide surface. The data are interpreted on the basis of electrochemical kinetics. 18496

3.8.2, 6.3.11

Some Abnormal Hydrogen Electrode Reactions. D. J. G. Ives. Can. J. Chem., **37,** No. 1, 213-221 (1959).

A study is made of the change of state of gold electrodes, owing to thermal de-activation in hydrogen, from normal behavior in relation to the hydrogen-evolution reaction to a state characterized by high positive rest potentials. Data obtained are confirmed by results with poisoned platinum electrodes.—MA. 18476

3.8.3, 5.9.4, 6.3.15

Anodic Polarization and Anodic Protection of Titanium in Hydrochloric and Sulfuric Acids. R. Otsuka. Scient. Pap. Inst. Phys. Chem. Res., **53,** 9-12 (1959) March.

Anodic passivity of titanium is investigated in hydrochloric and sulfuric acids by the potentiostatic method at room temperature. Titanium passivates easily even in such corrosive acids, and the anodic protection afforded is extremely effective even at elevated temperatures. —JSPS 18506

3.8.4, 6.3.20, 3.7.4

Reaction of Hydrogen with Zircoium-1 and -25 w/o Uranium Alloys. Harold E. Bigony, R. Robert Doig, Jr. and Horatio H. Krause, Jr. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-1359, July 6, 1959, 27 pp. Available from Office of Technical Services, Washington, D. C.

Hydrogen-absorption isotherms were measured over the range 535 to 835 C for zirconium-1 wt. percent and -25 wt. percent uranium alloys. X-ray-diffraction studies were made over approximately the same temperature range for the zirconium-1, -25, and 50 wt. percent uranium alloys. In general, the alloys resemble the zirconium-hydrogen system, modified by the presence of uranium. With 1 wt. percent uranium, the phase boundaries of the zirconium-hydrogen system are shifted to slightly lower hydrogen contents. With 25 wt. percent uranium, the first "two-phase" region shifts to a hydrogen content 20 wt. percent greater than in the zirconium-hydrogen system, while the second "two-phase" region is unchanged. The eutectoid temperature is increased from 547 to 601 C. Heats of solution of hydrogen in the alloys were found to range from —25.9 to —47.9 kcal/mole for the 1 wt. percent alloy, and from —30.7 to —50.6 kcal/mole for the 25 wt. percent alloy. The X-ray-diffraction data support the interpretation that, as hydrogen is absorbed, the alloys break down to form uranium and zirconium and the latter absorbs the hydrogen. The entire ternary isotherms could not be deduced from the data. However, three aspects appear certain: (1) the extent of the phase fields along the zirconium-hydrogen binary at 1 wt. percent uranium, (2) the existence of alpha zirconium, alpha uranium and ZrH_x three-phase fields at low temperatures, and (3) the existence of fields containing beta uranium and ZrH_x at higher temperatures for both the 25 and 50 wt. percent alloys. (auth)—NSA. 18338

3.8.4, 2.3.9, 5.4.5

Diffusion of Metal Ions Through Non-Conductive Coatings. J. Clavilier. Compt. rend., **248,** No. 10, 1508-1510 (1959).

A radio-tracer technique for measuring ionic diffusion through a non-conductive cellulose coating on a copper base is described.—RPI. 18322

3.8.4, 6.7.2, 6.2.5, 6.3.4, 3.2.2

Dry Oxidation of Steels and Refractory Alloys at Elevated Temperatures (to 1200 C). (In French.) S. Ferre. Rév. Met., **56,** 386-394 (1959) April.

Isothermal oxidation tests on 18-8 type steels, Nimonic-type alloys, cobalt-base alloys and other materials such as a titanium carbide-base cermet. Influence of duration of test and composition of alloy on weight increase; intergranular corrosion; classification of materials in order of susceptibility to oxidation. 9 references.—RML. 18374

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.5, 3.6.8, 4.3.2, 6.3.11

Some Features of the Cathode Process on Stainless Steel in Nitric Acid Solutions. (In Russian.) E. N. Mirolyubov, M. M. Kurtepov and N. D. Tomashov. Inst. of Physical Chemistry, Academy of Sciences, USSR. Doklady Akad. Nauk SSR, **125,** 1288-1291 (1959) April 21.

Cathode polarization curves were plotted for stainless steel (chromium steel with 17 to 28 percent chromium annealed at 760 C, and chromium-nickel steel of 18-8 type with niobium annealed at 1050 C) and platinum corrosion in 3 percent completely dissociated nitric acid and in 30 percent nitric acid containing non-dissociated homopolar molecules.—NSA. 18427

6.2.5, 8.1.2, 3.7.2

Stainless Steel in Architecture. (In German.) G. Hebbel and P. A. Huppertz. Industrie-Anzeiger, **81,** 747-750 (1959) June 19.

Composition and properties of several German stainless steels. Potential of iron-chromium alloys in air and rate of corrosion as a function of chromium content.—RML. 18462

6.2.5, 4.3.2, 3.2.2

Mechanism of Intercrystalline Corrosion of Stainless Steel in Nitric Acid. (In Russian.) A. I. Krasil'shchikov, L. M. Volchkova, I. K. Burtseva and V. D. Piyasunov. Doklady Akad. Nauk SSR, **125,** 1285-1287 (1959) April 21. English Translation of Journal Available from Consultants Bureau, Inc., 227 West 17th Street, New York 11, N. Y.

It is shown that a current appears between two stainless steel electrodes submerged into nitric acid solutions of various concentrations; the electrode in the stronger concentration acts as cathode and the electrode in the weaker solution acts as anode. Effects of various concentrations of nitric acid and various admixtures of Cr^{3+}, Cr^{6+}, and Fe^{3+} on the behavior of stainless steel at 60 C are shown graphically.—NSA. 18387

6.2.5, 3.7.3, 3.7.2, 4.3.2

Choice of Materials for Corrosion Resistant Welded Constructions: Stainless Steels of Low Carbon Content or Stabilized Steels. (In German.) Gunnar Lilljekvist. Chem. Rundschau, Supplement 3, **12,** 313-316 (1959) June 1.

Corrosion behavior of various titanium and niobium- stabilized and unstabilized 18-8 chromium-nickel-steels, with low carbon content, in 6 percent nitric acid. Corrosive attack, together with the formation of carbides during welding, are influenced by carbon content. Stabilized steels have slightly higher mechanical properties.—RML. 18384

6.2.5, 3.7.2, 4.3.2

Electrochemical Behavior of 18-8 Austenitic Stainless Steel with Molybdenum in Sulfuric Acid Solution. (In French.) Phillippe Berge. Compt. rend., **248,** 3557-3559 (1959) June 22.

Polarization curves of austenitic 18-8 stainless steel and 18-8 containing 3 percent molybdenum show the generally favorable effect of molybdenum on corrosion in sulfuric media. The 18-8 with molybdenum was definitely more passive. This may be because of the faster formation of an oxide layer.—NSA. 18342

6.2.5, 3.2.2, 3.5.3

New Stainless Steels Resist Pitting, Abrasion. R. B. Norden, Editor. Chem. Eng., **66,** 210, 212 (1959) June 15.

Properties of PH-55A, PH-55B and PH-55C stainless steels are tabulated and compared with other stainless steels. These metals offer high strength without service cold working and they are corrosion and abrasion resistant.—NSA.

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.5, 3.7.2, 3.5.9, 3.4.6

Oxidation and Contamination Reactions of Niobium and Niobium Alloys. William D. Klopp, Daniel J. Maykuth, Chester T. Sims and Robert I. Jaffee. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-1317, Feb. 3, 1959, 79 pp. Available from Office of Technical Services, Washington, D. C.

Niobium was found to react linearly with air (600 to 1200 C) and with oxygen (400 to 1400 C). At 1400 C, a very rapid reaction with oxygen was observed. Contamination hardening during oxidation was attributed to diffusion of oxygen into the metal from the predominantly niobium pentoxide scale. Alloying effects could be correlated with relative ionic size and valence of the alloy addition and with properties of the alloy-element oxides. Additions with smaller ionic size or higher valence improved oxidation behavior up to 15 at.% alloying. These additions included chromium, molybdenum tungsten, and vanadium. Size effects predominated over valence effects. At alloying levels greater than 15 at.% elements having solid stable oxides, such as titanium and zirconium, improved the oxidation behavior. Elements with volatile oxides, such as molybdenum, rhenium and vanadium, decreased the oxidation resistance when added in amounts greater than 15 at.%. The most effective binary additions for improving oxidation resistance were

chromium, molybdenum, titanium and vanadium. A molybdenum-chromium alloy oxidized about 20 percent slower than the best binary alloy. The degree of improvement for the best alloys over unalloyed niobium ranged from a hundredfold at 600 C to sixfold at 1200 C. The most effective additions were concluded to be those which form solid stable oxides of their own or which are capable of forming complex oxides such as spinels. (auth)—NSA. 18544

6.3.6, 3.6.2

Mechanism of Metallic Corrosion in Cracks and Crevices. Pt. 5. Corrosion of Copper and Copper Alloys. (In Russian.) I. K. Marshakov and I. L. Rozenfel'd. J. Phys. Chem, USSR (Zhur. Fiz. Khim), **33,** 219-223 (1959) Jan.

In copper and bronze intensified disintegration of the metal lies not in the crevice itself but on the external surface. Severe corrosion in a crack or crevice in copper and bronze is due to the presence of concentration cells. 9 references.—RML. 18400

6.3.10, 4.7, 3.5.9

New Alloy N Joins Hastelloy Family. F. S. Badger. Haynes Stellite Co. Chem. Eng., **66,** No. 9, 162, 164, 166 (1959) May 4.

Development and properties of a new nickel-molybdenum alloy for use as a container material for fused fluorides containing uranium are discussed. Tests prove that the alloy is resistant to corrosion from fluoride salts, oxidation in air and elevated temperatures.—NSA. 18255

6.3.10, 8.5.2

High Temperature Alloys for the Glass Industry. B. F. Richardson. Glass Ind., **40,** 421-422, 445 (1959) Aug.

Alloys are melted in vacuum induction furnace to remove gaseous impurities. These alloys have a nickel base with chromium, cobalt and molybdenum additions which strengthens the nickel and increases corrosion and oxidation resistance.—RML. 18515

6.3.15

Lubrication of Titanium. R. O. Lee and N. Fatica. Clevite Research Center for U. S. Wright Air Development Center, U. S. Air Force. Dec., 1957, 51 pp. Available from Office of Technical Service, U. S. Dept. of Commerce, Washington 25, D. C. (Order PB 131650).

Greater insight into the difficult problem of preventing galling and seizure in titanium was sought through a study of the nature of both untreated and altered titanium surfaces. Information was accumulated on the role of oxide film on titanium, the frictional properties of modified titanium coatings and the comparative wear resistance of the best surface treatment in the presence of various lubricants. Tests were run on the slip-stick machine and on the Shell four-ball wear tester. Among the more significant results, it was shown by tests on the slip-stick machine that the oxide layer on titanium is easily penetrated even at moderate loads. Moisture in the air generally acts as a lubricant and is an important factor in determining the frictional properties of titanium. Temperature also is an important factor in frictional properties. Tests on both the slip-stick and four-ball testers showed Halocarbon 11-14 to be the most effective lubricant on treated and untreated surfaces alike.—OTS. 15821

6.3.15, 3.2.3, 3.4.6

Utilization of Low Grade Titanium Sponge Produced by Kroll Process. Pt. 4. Corrosion of Titanium-Iron Alloys in Sulfur Dioxide at Elevated Temperatures. (In Japanese.) K. Hirayama & T. Takei, Scient. Pap. Inst. Phys. Chem. Res., **35,** No. 3, 235-241 (1959).

Authors studied the corrosion of titanium-iron alloys (FeO-16 percent) in sulfur dioxide gas at 1 atm pressure and temperatures up to 1000 C. 18-8 stainless steels have better sulfur dioxide corrosion resistance; the resistivity of the titanium alloy decreases as iron content increases. Corrosion proceeds rapidly at temperatures above 600 C and scaling is observable. The scale, mixture of oxides and sulphides, is compact, but is not enough adherent to the surface to be effective as protective film. The metal layer under the scale becomes hard and brittle by absorption of oxygen. Microscopic examination and other tests, show that corrosion proceeds by mutual diffusions of metal ions and negative ions.—JSPS. 18463

6.3.15, 4.3.2, 4.3.5, 4.4.2

Corrosion Resistance of Titanium and Titanium Alloys. (In Russian.) D. Mendeleeva. Khim. Nauk i Prom. (Chemical Science & Industry), **3,** No. 6, 803-807 (1959).

Resistance of titanium to corrosion in media of chlorine, chlorides and weak hydrochloric acid is greater than that of 18-8 stainless steel. The formation on the surface of titanium of a thin oxide film, due to its density and uniformity, protects the metal from further interaction with outer media. It is attacked by a number of mineral and organic acids. 23 references.—RML. 18440

6.3.15, 3.7.2, 4.3.2

Titanium Alloy Gets Protection from Noble Metal Additions. Iron Age, **183,** No. 16, 129-130 (1959) April 16.

Addition of palladium to titanium produces an alloy that is resistant to both reducing and oxidizing acids.—NSA. 18484

6.3.15, 6.3.20, 6.3.13, 6.3.5, 6.4.3

Corrosion Behaviour of Some of the Newer Metals. N. P. Inglis and J. B. Cotton. Eng. Materials and Design, **2,** 78-80 (1959) Feb.

Corrosion behavior of tantalum, niobium, titanium, zirconium and beryllium is discussed. The intrinsic reactivity of the metals is outlined and a chart is presented in which the comparative resistance to corrosion of the five metals is summarized. Their corrosion behavior is considered with reference to the formation of an oxide or surface film, raising of the potential and the mechanism of surface passivation. Mention is made of the behavior of titanium under an impressed current and the future possibilities of the metals are indicated. (auth)—NSA. 18482

6.3.17, 3.4.6, 3.5.9, 3.8.4

Kinetics of the Oxidation of Uranium by Carbon Dioxide. J. E. Antill and K. A. Peakall. Journal of the Less-Common Metals, **1,** 227-231 (1959) June.

Rates of oxidation over the range 500-1000 C. The rate increases with temperature from 500 to 780 C with a sudden marked increase when the metal is near or at the beta-gamma transition (772 C). At higher temperatures up to 1000 C the rate decreases with increasing temperature. 4 references.—RML. 18250

6.3.20, 3.5.9, 3.8.4

Diffusion of Oxygen in Alpha and Beta Zircaloy-2 and Zircaloy-3 at High Temperatures. M. W. Mallett, W. M. Albrecht and P. R. Wilson. Battelle Memorial Inst. J. Electrochem. Soc., **106,** No. 3, 181-184 (1959) March.

Diffusion rates of oxygen in alpha and beta Zircaloy-2 and Zircaloy-3 were determined in the range 1000 to 1500 C. For alpha Zircaloy-2, the variation of the diffusion coefficient, D, in cm^2/sec, with temperature is given by the equation $D_\alpha = 0.196 \exp(-41{,}000 \pm 1500/RT)$. For beta Zircaloy-2, $D_\beta = 0.0453 \exp(-28{,}200 \pm 2400/RT)$. Spot checks of the diffusion of oxygen in alpha and beta Zircaloy-3 to 1100 and 1400 C show that the rates are in close agreement with those for oxygen in Zircaloy-2. The diffusion coefficients for oxygen in beta Zircaloy-2 and Zircaloy-3 are about 10 times greater than those for nitrogen in high-purity beta zirconium. (auth)—NSA. 18401

6.3.20, 3.8.4, 2.3.5

Thin Film Formation on Zirconium. Robert E. Meyer. Oak Ridge National Lab. J. Electrochem. Soc., **106,** 930-935 (1959) Nov.

Using an electrochemical method, rates of film growth in oxygenated sodium sulfate solutions have been measured on polycrystalline zirconium at temperatures ranging from 25 to 88 C. The resulting rate-time plots are roughly hyperbolic. A model is proposed which when treated by electrode kinetics is shown to give this type of behavior. 18428

6.3.20, 4.6.2, 3.7.3

High-Temperature Water and Steam-Corrosion Behavior of Zirconium-Uranium Alloys. Stanley Kass. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-TM-167, July, 1959, 23 pp. Available from Office of Technical Services, Washington, D. C.

Weight change vs time curves expressing the corrosion behavior of zirconium alloys containing additions of 10 through 60 wt. percent uranium tested in 600 and 680 F water and in 750 F steam at 1500 psi are presented. The effects of various heat treatments on the subsequent corrosion properties are also included. (auth)—NSA. 18470

6.3.20, 8.8.5, 4.6.2

Investigation of the Effects of Fabrication Variables on the Corrosion Resistance of Zircaloy-2. H. S. Kalish, H. M. Cobb and D. W. Coate. Olin Mathieson Chemical Corp. U. S. Atomic Energy Commission Pubn., AECU-4093, March 16, 1959, 134 pp. Available from Office of Technical Services, Washington 25, D. C.

An investigation was conducted of the effect of melting and fabrication variables on the corrosion of Zircaloy-2 in 750 F steam at 1500 psi. Two 12 in. diameter production-type ingots and three 4 in. diameter laboratory type ingots were produced representing primary and secondary melting in 75 percent helium-25 percent argon atmosphere, primary melting in 75 percent helium-25 percent argon and secondary melting in vacuum, and primary and secondary melting in vacuum. Variations were performed in the ingot forging procedures, hot rolling temperatures, homogenization treatment and final heat treatment of the hot rolled Zircaloy-2 strip. Corrosion data were

obtained on the strip produced from the large ingots after intervals of 14, 28, 56, 70, 84 and 112-day intervals. Corrosion data were obtained on strip produced from the small ingots at 14 and 28-day intervals. (auth)—NSA. 18467

7. EQUIPMENT

7.5 Containers

7.5.5, 3.4.8

Corrosion of Oil-Industry Storage Tanks. J. S. Hume. Continental Oil Co. Oil and Gas J., **55,** No. 45, 153-154, 156, 158, 160 (1957) Nov. 11.

Results on survey of tank corrosion. Severe corrosion in vapor zone of tanks is not necessarily a function of sulfur content, as examples of severe corrosion were reported wherein stored crudes and distillates contained sulfur over wide range of 0.02-3.0%. One company predicts severity of corrosion on basis of hydrogen sulfide content of stored materials. Chief corrodents are hydrogen sulfide, water and oxygen. Factors which increase concentration of these corrodents tend to increase corrosion severity. Aluminum, galvanized steel, copper bearing steel and wrought iron roofs were used in corrosive services. Use of protective barriers and chemical treatment is discussed. A selected bibliography of tank-corrosion articles and abstracts of these articles are given.—INCO. 16169

7.5.4, 4.4.6, 5.4.5

Improved Coatings for the Protection of Water-Sealed Gas Holders. Corrosion Prevention and Control, **5,** No. 2, 44-46 (1958) Feb.

One of most persistent problems in gas works operation is protection of lower lifts of water-sealed gas holders. With holder at maximum capacity, products which have condensed on interior surfaces escape into water seal surrounding each lift. Condensate, known as solvene, consists of many substances such as benzine and other hydrocarbons, naphthaline and tar acids. It viciously attacks conventional oil-type paints. Tests were initiated on coating system based on Epikote resin. System employed was 2-coat application of Anotect Metallic Primer. Another case involved use of 2 coats of Anotect Metallic Primer and 1 coat of Brymod C. B. enamel. Excellent service was obtained. Photographs.—INCO. 17205

7.6 Unit Process Equipment

7.6.4, 3.5.2, 3.4.8, 4.2.3

Deposit Formation and External Corrosion in Steam Generators. (In Italian.) F. Mastrorazio. Shell Italiana S.p.A. Riv. Combustibili, **13,** 347-363 (1959) May.

Deposits and corrosion in the high temperature areas of boilers may essentially be ascribed to fuel ash components, while in low temperature areas these problems are mainly caused by sulfur. Methods to alleviate these problems by design, the use of corrosion-proof materials, operation and maintenance, the use of additives, etc. are reviewed from the point of view of efficiency, advantages, and possible applications. 18431

7.6.4

Recent Research on Boiler Tube Corrosion. E. C. Potter. Paper before Soc. Chem. Industry, Corrosion Group, Manchester, England, March 29, 1958. Chem. and Ind., No. 10, 308-314 (1959) March 7.

Presents statistical, mechanistic and experimental approaches to problem of boiler tube corrosion in Britain. Results of boiler-tube corrosion survey made by British Electricity Authority are analyzed. Distribution of attack rather than amount determines serviceability of boiler tube; an otherwise insignificant amount of corrosion confined to small enough area can cause stoppage of large amount of power plant. On the average, a power station with corrosion may expect to have 2/3rds of its boiler corroded. Graph plots probability of boiler-tube corrosion while tables show time variation of boiler-tube corrosion and newly corroded boilers year by year (1937-1955). Mechanism by which dense, adherent magnetic iron oxide grows on steel composition on magnetite formation are considered. Description is given of an experimental steam generator for tube-corrosion testing designed by British Electricity Authority in 1953 and erected by International Combustion Ltd. at power-station site in London. Boiler, which has novel features as corrosion-testing equipment, has been increasing operation since 1957 and operates automatically at any chosen steam pressure up to 2000 psi under controllable water conditions with heat transfer rates up to 200,000 Btu/sq. ft./hr. over experimental surfaces. Diagram. —INCO. 18494

7.6.4, 4.4.7, 5.5.3

Corrosion in Steam Boilers. (In Swedish.) Torsten Widell. Tekn. Fören i Finland Förh., **77,** 209-218 (1957) Sept.

Corrosion due to composition of modern heavy oils and their deposits in the air-preheater. The formation of sulfuric acid and sulfur trioxide. Analysis of the corrosive action at low and high temperatures. Corrosion-preventing oil additives. 23 references.—MR. 17080

7.6.4, 4.4.7, 8.2.2, 5.11, 5.8.1

Experiences in Combating the Corrosion Caused by Fuel Oil on the Low Temperature Surfaces in Boilers. (In Italian.) A. Grondona and G. P. Marcucci. Esso Standard Italiana. Riv. Combustibili, **13,** 364-378 (1959) May.

Low temperature surface corrosion of boilers due to sulfur in fuel oils can be held to acceptable limits by design changes which result in lower efficiency or by additives which will lower the dew point of the fumes, where dolomite has proved to be one of the most efficient additives. The design changes which are reviewed include cold air bypass, hot air recirculation, gas recirculation and combined stream of gas and air. The results of actual tests with ammonia, lime, dolomite, pyridine and magnesium oxide as additives are reported. Results obtained in 25 electric power plants throughout the world are reviewed and details of tests made at the Marchwood Power Station (England) are given. 18267

7.6.4, 4.3.3, 4.2.3, 3.4.8

Vanadium—A Bad Actor in Fuels. R. S. Norris. Marine Engineering/Log, **64,** No. 4, 68-70 (1959) April.

Corrosion of air preheaters, superheater tubes and tube supports is linked to vanadium content of residual fuels. Boiler slag and deposits are high in vanadium pentoxide. In molten state, vanadium pentoxide causes corrosive attack by fluxing with protective oxide layer on steel or alloy and leaving bare metal exposed to corrosive oxidation and sulfidation by sodium, vanadium and sulfur. Vanadium is powerful catalyst for reaction of sulfur dioxide plus oxygen to form sulfur trioxide which condenses to form sulfuric acid. Graph shows relationship between sulfur in fuel, sulfur trioxide in flue gas, metal temperature and dew point. In presence of sodium, vanadium pentoxide may form vanadates of low melting point. Effectiveness of additives is discussed. —INCO. 18545

7.6.4, 4.6.2

Corrosion of Boilers. (In German.) K. Kovacs. Metalloberfläche, **13,** 167-168 (1959) June.

Steam corrosion lowers the resistance of steel surfaces to further development of corrosion. Protective layer of magnetite is formed only up to 570 C and is then replaced by wustite which has a reduced protective capacity. 5 references.—RML. 18394

7.6.5, 8.5.3, 4.3.2, 6.2.3, 6.3.10

Evaporator Corrosion. H. E. Jacoby and H. G. Lankenau. Paper before TAPPI, 13th Eng. Conf., Portland, Oregon, July 28-August 1, 1958. TAPPI, **42,** No. 7, 168A-171A (1959) July.

Describes several typical cases illustrating exteremes in corrosion problems experienced with pulp mill black liquor evaporators, and correlates them to mill liquor system. Experience with carbon steel, Type 304, Type 316 and Inconel components is discussed. Susceptibility of Type 304 tubes to chemical boilout attack (hydrochloric acid) and to stress corrosion is pointed out.—INCO. 18468

8. INDUSTRIES

8.4 Group 4

8.4.5

Metals for the Atomic Boiler. B. Lustman. Westinghouse Electric Corp. Metal Progress, **75,** No. 5, 97-102 (1959) May.

Some highlights of many developments in metallurgical materials which were necessary for Shippingport Pressurized Water Reactor plant are summarized. Blanket fuel fabrication, fretting and mechanical wear, cracking of stainless steel, selection of materials for pressure vessel, and coolant contamination are considered. Uranium dioxide blanket fuel pellets are protected from contact with water by sheathing in Zircaloy-2. Pressure vessel is lined with ¼-in. Type 304 bonded to manganese-molybdenum firebox steel slab (SA-302 Grade B) by hot rolling. Primary loop piping and heat exchanger tubing are of Type 304. Thermocouples are sheathed in stainless steel. Fretting in latch assembly consisting of Type 304 latch mechanically fastened to Zircaloy-2 fuel clusters was eliminated by a modified design. Measurements were made of activation of corrosion products formed on stainless steel surface of plant, sloughed from surface in contact with coolant, and transported through core to other parts of system where they can deposit. Amount of such elements as cobalt in metals and alloys should be minimized. Illustrations.—INCO. 18399

8.4.2, 5.2.1

Reducing Unaccounted-for Gas by a Leakage Control and Corrosion Prevention Program. T. E. Adams. Consoli-

dated Gas Utilities Corp. Gas, **35,** No. 3, 72-74 (1959) March.

Some of the methods used by Consolidated Gas Utilities Corp. in this leakage and control program are briefly covered. Mill coated and wrapped pipe has been used for 8 years on maintenance and construction projects in transmission and distribution systems. Anodes are installed at time of construction except on major transmission jobs. New pipe is insulated from sections of old pipe and meter installations are insulated at point of consumer's premises. Pipe-to-soil check is made twice a year to verify protective potential. On older transmission lines, surface potential or 2-electrode method is proving very successful in locating hot spots, replacement sections and anode locations. Forms used for transmission line survey and for distribution surveys and anode installations are reproduced. Cathodic protection memo lists instructions prepared to clarify cathodic protection program and to provide personnel with information as to what they are to expect from program and cathodic technicians.—INCO. 18297

8.4.3, 5.8.1, 6.2.3

For Oil Well Acidizing . . . Acetylenic Corrosion Inhibitors. G. L. Foster, B. D. Oakes and C. H. Kucers. Paper before American Chemical Society, 13th Southwest Regional Mtg., Tulsa, Oklahoma, December 6, 1957. Ind. & Eng. Chem., **51,** No. 7, 825-828 (1959) July.

As oil wells are drilled deeper, and higher temperatures are encountered, inhibitors to prevent corrosion of oil well casing and tubing during acidizing have become more important. Acetylenic compounds were discovered to be effective inhibitors. Paper describes systematic substitution of each reactive site in the propargyl alcohol molecule, and how this substitution affects corrosion inhibition. Theory indicates that triple bond is focal point of this inhibitory action, and experimental results confirm it. Corrosion rates were determined on AISI 1020 mild steel coupons. Tables, 10 references.—INCO. 18363

8.4.5, 3.4.3

HRP-CPP: Dissolution of Zirconium and Stainless Steel Corrosion Product Oxides. J. W. Snider and P. A. Haas. Oak Ridge National Lab. U. S. Atomic Energy Commission Pubn., CF-58-8-28, August 5, 1958, 16 pp. Available from Office of Technical Services, U .S. Dept. of Commerce, Washington, D. C.

Dissolution methods were developed to permit representative sampling of the slurry of corrosion and fission products collected by the HRT chemical processing plant. The procedure selected for HRT-CPP application was to use 15 ml of 10.8 M sulfuric acid per gram of solids with agitation by boiling in a tantalum-lined dissolver. (auth)—NSA. 18046

8.4.5, 3.4.3

HRT-Chemical Plant Run 16 Summary. O. O. Yarbro. Oak Ridge National Lab. U. S. Atomic Energy Commission Pubn., CF-58-10-111, October 9, 1958, 15 pp. Available from Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C.

HRT chemical plant hydroclone loop, designed for the continuous removal of fission and corrosion product solids from the HRT, began radive operation during reactor run 15. Cell equipment was operated without difficulty and only minor troubles were encountered with auxiliary equipment. Operating variables, and data on corrosion product solids' removal during three periods of operation are summarized. Approximately 20 percent of the stainless steel corrosion products produced in the reactor were removed by the hydroclone. (auth)—NSA. 18153

8.4.5, 6.3.11

PWR Alternate Control Rod Material Program. Monthly Report No. 10 for March 15 to April 15, 1957. I. Cohen. Westinghouse Electric Corp. U. S. Atomic Energy Commission Pubn., WAPD-PWR-PMM-1207, April 15, 1957 (Changed from Official Use Only June 25, 1959) 44 pp. Available from Office of Technical Services, U. S. Department of Commerce, Washington, D. C.

A number of silver-indium-cadmium alloys was prepared for evaluation as possible control rod material. The physical properties, corrosion resistance, fabricability, structure and physics worth of these alloys are reported.—NSA. 18312

8.4.5, 6.2.1, 6.4.2, 6.4.4

Behavior of Structural Materials Exposed to an Organic-Moderated Reactor Environment. N. J. Gioseffi and H. E. Kline. North American Aviation, Inc. Nuclear Sci. and Eng., **2,** No. 1, Suppl. 25-26 (1959) June.

Behavior of various structural materials in an organic-moderated and cooled reactor was determined under realistic operating conditions. Tests were run in the OMRE operating at 6-Mwh. Two in-pile dummy fuel elements and an out-of-pile section of a bypass line were loaded with mechanical and corrosion test specimens. Tensile strength, yield strength, reduction in area, elongation and impact were measured after exposure for specimens of 1020 carbon steel, 4130 alloy steel, 304 stainless steel, 304 stainless steel sensitized 2 hours at 1200 F, 410 stainless steel, aluminum and magnesium.—NSA. 18273

8.4.3, 5.4.5, 5.8.2, 3.5.2, 3.2.2

Unique Program Combats External Tubing Corrosion in California. P. W. Hill and H. J. Kipps. Signal Oil & Gas Co. World Oil, **148,** No. 4, 98-102 (1959) Mar.

Deposit attack corrosion problem in annulus of directionally-drilled wells in Redondo Beach, Calif., area is combatted by a 3-phase control program involving changing well completion practices, plastic coating exterior surface of tubing strings, and injection of inhibitors, using an automatically controlled chemical-wash oil injection system, which protects uncoated equipment in wells. Combination of carbon dioxide and hydrogen sulfide in gases produced and formation brine caused serious corrosion attack. Severity of corrosion problem which developed was caused by clay water drilling mud left in well annulus after completion. Pitting attack on outside of tubing was localized under mud deposits. Scale accumulating in pits under mud was found to be corrosion products which accelerated pitting attack. This deposit attack was not detected by ordinary corrosion rate evaluation procedures and corrosion pits under mud and scale had to be located by electromagnetic inspection. Plastic coating of tubing and changes in completion practice have minimized attack; insufficient time has elapsed to thoroughly evaluate inhibitor treatment but it seems beneficial throughout entire system. Illustrations.—INCO. 18451

8.4.5, 4.7, 2.3.9, 2.3.6, 2.3.4

Improvement of Several Analytical Methods Used in the Nuclear Metal Industry. (In French.) Jacques Robin. Centre de recherches d'Ugine, Lyon. Énergie nucléaire, **1,** 72-76 (1959) May-June.

Several examples of analytical control related to the nuclear energy industry are given. Corrosion of steel by molten sodium at high temperatures can be evaluated either by direct study of the steel (weight variation or metallography) or by analysis of the sodium before, during, and after the test. The apparatus used for sampling the sodium and its operation are described. For purity control of zirconium and its alloys—determination of low and very low concentrations of impurities—the spectrographic method is preferable to chemical analysis. Determinations run on uranium tetrafluoride are also discussed. (tr-auth). —NSA. 18521

8.4.5, 6.2.5, 4.3.4

Operation of the HRT Mockup with Boiling Fuel in a Titanium Pressurizer, Run CS-23. R. B. Korsmeyer and P. H. Harley. Oak Ridge National Lab. U. S. Atomic Energy Commission Pubn., CF-59-5-13, May 19, 1959, 8 pp. Available from Office of Technical Services, Washington, D. C.

The 0.045 *m* uranyl sulfate, 0.036 *m* cupric sulfate, 0.025 *m* sulfuric acid solution (HRT fuel composition) was chemically stable during 1,866 hr. of operation at 280 C and 1500 psi.

The generalized stainless steel corrosion rate during operation at 2800 and 1500 psi was 0.6 mpy for the first 700 hr. and 1.6 mpy for the next 1,166 hr. The average rate during the period when excursions were made into the two-phase region was 3.0 mpy. The apparent increase in corrosion rate is not easily explained because no unusual attack could be found on inspection of the stainless steel surfaces, particularly in the vicinity of the titanium heat exchanger.—NSA. 18395

8.4.5, 4.7

Construction Material for the Hydrofluorinator of the Fluoride-Volatility Process. Paul D. Miller, Charles L. Petersen, Oliver M. Stewart, Elmer F. Stephan and Frederick W. Fink. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-1348, June 3, 1959, 44 pp. Available from Office of Technical Services, Washington, D. C.

Fuel elements clad with zirconium or containing zirconium as a diluent can be recovered by a fluoride-volatility process. The first step consists of hydrofluorination of the elements in a bath of molten fluoride salts using an hydrofluoric acid sparge. In this case the two salt systems considered were sodium fluoride-zirconium fluoride and sodium fluoride-lithium fluoride. Materials evaluated at Battelle for possible use in the construction of this hydrofluorinator include Inconel, "A" Nickel, copper, silver, Monel, Hastelloy B, Hastelloy W, INOR-1 and INOR-8. The metals were exposed to molten fluoride salts through which hydrofluoric acid was bubbled continuously. The data indicate that the sodium fluoride-lithium fluoride systems

are much more corrosive than the sodium fluoride-zirconium fluoride system. The systems are most corrosive when the alkali fluoride component is high. An elevation in temperature increases the corrosion significantly as does an increase in the hydrofluoric acid flow rate. Hydrogen in the hydrofluoric acid flow stream retards the corrosion of the sodium-zirconium salts significantly, but appears to have less effect on the sodium-lithium systems. The areas at the interface of the liquid and vapor phases were most seriously damaged under the exposure conditions usually used. However, appreciable reduction in attack was experienced when zirconium was actually hydro-fluorinated. INOR-8 was the most promising of the materials evaluated. (auth)—NSA. 18424

8.4.5

Why the PAR Homogeneous Project Was Suspended. W. E. Johnson and S. C. Townsend. Nucleonics, **17,** No. 2, 61-63 (1959) Feb.

On December 16, 1958, Pennsylvania Power & Light Co. and Westinghouse Electric Corp. announced suspension of Pennsylvania Advanced Reactor Project (PAR) because construction of a large-scale aqueous homogeneous plant was technically infeasible at that time. It was recommended that prototype plant development and operating experience should be part of further development of PAR reactor type. Brief resume of accomplishments of project and reasons leading to its suspension are given. Reactor cycle is aqueous homogeneous system based on thorium-uranium cycle; suspension of oxides of thorium and uranium in heavy water flows through a single-region spherical vessel. 7 major problems existing at end of 1958 were gaseous recombination, effects of irradiation on slurry properties, reactor-vessel hydraulics, corrosion-erosion, stress corrosion, reactor startup and plant layout and maintenance; indication of progress made toward their solution is detailed. Need for corrosion-erosion tests on impellers made of Zircaloy or titanium and problem of chloride stress corrosion are included. Illustrations, flow diagram. —INCO. 18479

8.6 Group 6

8.6.1, 8.6.2

How Blackstone Beat Corrosion. R. L. Carlson. Blackstone Corp. Metal Products Mfg., **14,** No. 5, 56-57 (1957) May.

Synthetic detergents become rust catalysts when used as washing agents in automatic machines which require an outer tank or drain casing for water in addition to usual porcelain enameled or stainless steel washer tub. Phosphatizing, galvanizing and usual primer coat paints are ineffective. Blackstone Corp. uses a plastisol protective substance that is plastic enough to find its way into smallest corners of washer tank and around welded bottom seams. Finish has qualities of durability and resilience to withstand hard and long home use. Photos.—INCO. 16163

8.6.2, 5.3.4

Modern Detergents and Hot Galvanization. (In German.) Heinz Bablik and M. Belohlavy. Werkstoffe u. Korrosion, 8, 742-746 (1957) Dec.

Detergents containing polyphosphates attack hot galvanized surfaces.—MR. 16138

8.6.3

Constructional Materials for the Textile Industry and Their Protection. F. Podbreznik. Zastita Materijala, **6,** No. 74-75 (1958).

The corrosive agents present in the atmosphere of textile industry premises are discussed. Various protective procedures are given for the machinery and containers.—RPI. 16694

8.9 Group 9

8.9.3, 5.4.10, 5.2.1, 4.5.1

Fighting Corrosion in the Desert. F. M. Maasry. Trans-Arabian Pipe Line Co. Oil & Gas J., **57,** No. 25, 124, 126, 128 (1959) June 15.

Corrosion mitigation of 30-31-in. Trans-Arabian pipeline is complicated and difficult because pipe is exposed to varied corrosive conditions. All buried sections of main line were given a standard asphalt coating. In rocky areas heavy asbestos-felt rock shield was used for supplementary protection. Subsequent inspections revealed much of pipe coating on line to be of only fair quality due to 3 major causes; soil stresses exerted on asphalt; improper application of treatment resulting in an uneven spray of dope around pipe; and inadequate bonding between steel pipe and coating existing along a major portion of buried line. Cathodic protection program was started as soon as pipe was laid in ground. Most economical spacing between cathodic-protection stations was found to be 11 miles. Corrosion control on 245.72 mile buried section, on short buried sections, and on submarine lines is described. Lead alloy anodes in cable form are being used for submarine berths. Other marine facilities, such as barge, tugs, buoys, and pier are protected with magnesium and aluminum anodes.—INCO. 18411

8.9.2, 5.3.4, 5.4.8, 5.9.4

Chemical and Electrochemical Protection in the Automobile Industry. R. Vacher. Corrosion et Anti-Corrosion, **6,** No. 9, 318-328 (1958); Bull. Brit. Non-Ferrous Metals Res. Assoc., **39,** No. 354, 13 (1959). (In French.)

Subjects discussed include corrosion protection, considering decorative effect; chromium plating; chemical and electrochemical brightening (steel, zinc alloys, copper, brass); anodic oxidation of aluminum and its alloys; protective methods not concerned with decorative effect; galvanizing, cadmium plating, tinning, phosphating; and coatings for improved physical and mechanical properties.—RPI. 17638

8.9.3

Pipeline Corrosion. A Practical Example of Its Control. R. F. U. Icely. Pipe Line News, **31,** 41-44 (1959) March.

A Montreal plant recently experienced a complete and unexpected shut down of all the major processing units due to corrosion of an underground raw material supply line. It is believed that an account of the failure and the subsequent investigation, together with the application of well known corrosion prevention principles, will be of interest to all corrosion engineers as a practical example of the application of their particular branch of engineering.—BTR. 17712

8.9.5, 4.2.5, 5.4.5, 5.9.3

Corrosion Prevention for Marine Equipment. R. P. Devoluy. Glidden Co. Ind. & Eng. Chem., **51,** No. 5, 79A-80A (1959) May.

Preservation of floating equipment and shoreside structures has presented plant maintenance men with marine corrosion problems. Timely maintenance tips are given, with emphasis on barge corrosion problems. Barges built to carry corrosive cargoes and/or trading in corrosive waters should have their protection planned at drawing board. Mill scale should be removed, preferably by sandblasting completed barge just prior to painting. A good alternative is to pickel plating and then prime it with 2 coats designed to last through construction period. Table lists 4 types of paint systems that have been successful in barge painting. Selection of paint systems according to service conditions is tabulated. Antifouling paints should be omitted whenever possible, because they can contribute to bottom pitting. Painting under adverse conditions that normally prevail in shipyard repair work and progress in formulation of more durable paints to make them safer and easier to apply, are considered.—INCO. 18357

8.9.5, 5.2.1, 3.6.5

Some Features of Electric Potential of Ship Hulls and Propeller Shaft Lines. (In Japanese.) Hideo Kada and Tokizo Miyajima. Corrosion Engineering (Japan), **8,** No. 5, 195-197 (1959) May.

It has been observed that ship hulls potential varies according to whether the ship is running or staying. Such potential difference may be attributed to the fact that the propeller shaft and the ship hulls are insulated by the oil and water films on rubbing surfaces by shaft rotation. Consequently, cathodic protection should be applied to the propeller shaft system. 18472

8.9.5, 5.2.2

Zinc Anode Cathodic Protection System on the USS Wahoo. R. C. Francis. Bureau of Ships. Bureau Ships J., **7,** No. 12, 14-17 (1959) April.

A zinc anode cathodic protection system gave excellent protection against electrolytic corrosion during a 27-month service test on USS Wahoo (Dec. 1954-Mar. 1957). Although some corrosion was noted under superstructure and in fairwater at end of test, this damage was minor when it was compared with severe corrosion that occurred on a control submarine, USS Tang, in a 13-month period (similar cathodic protection system was later installed under superstructure and in fairwater of USS Tang). Results of complete inspection of both ships are detailed. Zinc anodes are now being specified for protection of free-flooding areas under superstructure, in fairwater, in ballast tanks near tank tops, and in other areas where there are concentrations of dissimilar metals. Quantity is determined on basis of providing a current density of 2 millamps per sq ft for steel or aluminum surfaces and 15 millamps per sq ft for bronze or other nonferrous metals. On submarines with aluminum superstructure or fairwater, zinc anodes should be installed on steel plating near aluminum-steel junctions and not on aluminum itself. Magnesium anodes and impressed current systems are being service-tested for underbody protection. Photos illustrate fouling, paint damage, corrosion of superstructure support cleats, oxide deposits on aluminum structure and cable clamp deterioration. —INCO. 18265

NATIONAL ASSOCIATION of CORROSION ENGINEERS

Executive Offices: 1061 M & M Bldg., Houston 2, Texas

Telephone CApitol 4-6108

Executive Secretary ..... T. J. HULL

Assistant Secretary and Exhibition Manager ..... R. W. HUFF, JR.

Technical Committee Secretary ..... J. F. VANDER HENST, JR.

Administrative Assistant for Regions and Sections ..... G. A. ROLAK

Publication Director ..... NORMAN E. HAMNER

Editorial Assistant ..... DALE MILLER

Inquiries regarding membership, and all general correspondence should be directed to the Executive Secretary at the administrative headquarters of the National Association of Corrosion Engineers at 1061 M & M Building, No. 1 Main Street, Houston 2, Texas.

•

The National Association of Corrosion Engineers is a non-profit, scientific and research association of individuals and companies concerned with corrosion or interested in it, whose objects are:

(a) To promote the prevention of corrosion, thereby curtailing economic waste and conserving natural resources.

(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

(f) To contribute to industrial and public safety by promoting the prevention of corrosion as a cause of accidents.

(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

(h) To invite a wide diversity of memberships, thereby insuring reciprocal benefits between industries and governmental groups as well as between individuals and corporations.

It is an incorporated association without capital stock, chartered under the laws of Texas. Its affairs are governed by a Board of Directors, elected by the general membership. Officers and elected directors are nominated by a nominating committee in accordance with the articles of organization. Election is by the membership.

Advertising and Editorial Offices of CORROSION

Address all correspondence concerning advertising, circulation and editorial matters relating to CORROSION to the NACE executive offices, 1061 M & M Building, Houston 2, Texas. Inquiries concerning and orders for reprints of technical information published in CORROSION should be sent to this address also.

OFFICERS and DIRECTORS

•

OFFICERS

President ..... GEORGE E. BEST
Manufacturing Chemists' Assoc., Inc, Washington, D. C.

Vice President ..... EDWARD C. GRECO
United Gas Corporation, Shreveport, La.

Treasurer ..... C. G. GRIBBLE
Metal Goods Corporation, Houston, Texas

Executive Secretary ..... T. J. HULL
1061 M & M Bldg., Houston, Texas

DIRECTORS

Past-President

HUGH P. GODARD 1960-61
Aluminium Laboratories, Ltd., Kingston, Ont., Canada

Representing Active Membership

R. McFARLAND, JR. 1958-61
Hills-McCanna Company, Chicago, Ill.

T. J. MAITLAND 1960-63
American Telephone & Telegraph Company, New York, N. Y.

J. P. BARRETT 1959-62
Pan American Petroleum Corp., Tulsa, Okla.

E. L. SIMONS 1959-62
General Electric Co., Schenectady, N. Y.

Representing Corporate Membership

L. W. GLEEKMAN 1960-61
Wyandotte Chemicals Corporation, Wyandotte, Mich.

L. C. WASSON 1958-61
A. O. Smith Corp., Milwaukee, Wis.

J. E. RENCH 1960-63
Napko Corporation, Houston, Texas

J. S. DORSEY 1960-63
Southern California Gas Co., Los Angeles, Cal.

GUY F. WILLIAMS 1959-62
Dowell Incorporated, Tulsa, Okla.

Representing Regional Divisions

E. H. TANDY ..... (Western) 1958-61
Standard Oil Co. of California, El Segundo, Cal.

A. B. SMITH ..... (Southeast) 1960-63
Amercoat Corp., Jacksonville, Fla.

J. D. BIRD ..... (Northeast) 1960-63
The Dampney Company, Hyde Park, Boston, Mass.

E. F. MOORMAN ..... (North Central) 1959-62
International Harvester Co., Chicago, Ill.

J. A. CALDWELL ..... (South Central) 1959-62
Humble Oil & Refining Co., Houston, Texas

T. R. B. WATSON ..... (Canadian) 1959-62
Corrosion Service Limited, Toronto, Ont., Canada

Directors Ex Officio

W. F. FAIR, Chairman Regional Management Committee
Tar Products Division, Koppers, Inc., Verona, Pa.

R. A. BRANNON, Chairman Policy and Planning Committee
Humble Pipe Line Co., Houston, Texas

R. S. TRESEDER, Chairman Publications Committee
Shell Development Co., Emeryville, Cal.

T. J. MAITLAND, Chairman Technical Practices Committee
American Telephone & Telegraph Co., New York, N. Y.

Corrosion

OFFICIAL MONTHLY PUBLICATION

National Association of Corrosion Engineers

An Association of Individuals and Organizations Concerned with Control of Corrosion

1061 M & M Building Houston 2, Texas

Vol. 16 July, 1960 No. 7

Ceramic Coatings for High Temperature Service*

By S. W. BRADSTREET, JR.

Abstract

Several types of coatings may be used for service in extreme thermal environments. For moderate temperatures (to about 1700 C) for short time periods, these coatings may be rather simple refractory layers. Under the more severe conditions of ramjet and rocket operation, reinforced materials, graded substrate-coating interfaces, or multilayers are required. Where thermal gradients are severe and where high shear stresses and abrasion exist, composites must be used which utilize controlled ablation.

The principles which appear to dominate the attachment of a ceramic coating to a variety of substrates are reviewed, and the deficiencies and advantages of different combinations are discussed. Principles for "tailoring" protective coatings for refractory metals is suggested, and a flame-sprayed ceramic coating of potential value as a combustion catalyst is used to illustrate these principles. 5.4.2

About the Author

S. W. BRADSTREET, JR., is Supervisor, Inorganic Technology, Armour Research Foundation, Chicago, Ill. He received his BS and B Chem degrees from Cornell University and an MS from California Institute of Technology. His experience includes five years as research metallurgist with a manufacturer of dairy equipment, five years of military service, a year as production manager for a lead products manufacturer, and two years of chemical engineering with a carbon electrode manufacturer before joining the Foundation in 1948. Mr. Bradstreet has been associated with a wide variety of research projects involving inorganic materials ranging from boiler scale to graphite, and composite materials including porcelain enamels, special glasses, superfractories, flake glass laminates, rocket nozzles, inorganic foams, adhesives, and coatings. He is co-inventor of "Solution Ceramics," "Slurry Ceramics," and "Flame Ceramics" processes, and is a member of the American and British Ceramic Societies and the American Rocket Society.

A CERAMIC coating must meet three requirements if it is to protect its substrate in a thermal environment:

1. It must conform to the substrate
2. It must adhere to the substrate
3. It must insulate and protect the substrate

Conformity

The precise mechanisms for obtaining an adherent layer of one solid upon another are not completely understood. Such terms as "mechanical," "chemical," and "lattice" bonding are freely used but appear to have been inadequately defined.

In order for any submicroscopic bonding to occur, the molecules or atoms of the dissimilar layers must approach to within bonding distance of each other. In all known cases, this requires that one layer, usually called the coating, be applied essentially as a fluid. (Exceptions to this are permissible only when precise conformity of mating solid surfaces can be obtained.)

The electromagnetic attraction of a liquid to a solid surface is called "wetting." The ability of a fusible glass to wet metallic surfaces has been established with glazes and porcelain enamels. The principles of electroplating and vapor deposition need not be reviewed here, beyond making the observation that forming a solid from its individual atoms or molecules involves processes identical to those of solidifying a molten material.

Where the coating particles are larger than molecules they may still retain enough surface energy to accomplish wetting. In colloidal suspensions this surface energy resides in the envelope of fluid solvent or vehicle, and is released by flocculation or precipitation reactions. A similar mechanism is exhibited in the sintering of ceramic particles at moderate temperatures,[1] in the bonding of particles in powder metallurgy, and in coating processes such as flame-spraying, at moderate temperatures or high pressures. Wetting of this kind, however, occurs over a limited area.

As the particle size increases, more energy is required to produce wetting contact. There is, therefore, a critical combination of particle size and energy content which is needed to produce conformity to the substrate and to the layer of coating already deposited.[2] For a typical ceramic material such as zirconia this critical size appears to be less than 0.01 micron at room temperature and 0.1 micron at 1500 C; larger particles do not sinter to maximum density until they begin to melt. If the particles are subjected to strong pressure or are violently impacted against the substrate, larger particles can be used at lower temperatures. This phenomenon is exploited in powder metallurgy and in flame-spraying.[3]

There are at present no techniques for quantitative measurement of the wetting phenomenon on this submicroscopic scale, since the interfacial tension between the two materials cannot be separated from the surface energy of the particle. The action may be illustrated, however, by the analogy of bonding a granite or dolomite crushed stone to a paving asphalt. When hot enough to be considered molten, the asphalt does not completely wet the aggregate, and bonding is poor. If the same heated asphalt is made into an aqueous emulsion it is found that this wets the stone even at ordinary temperatures, and upon subsequent drying the asphalt is firmly bonded to it.

This analogy illustrates the principle of colloidal bonding and polar wetting which is the basis for attaching most ceramic slips, suspensions, adhesives, and cements to a substrate for subsequent firing. The "vehicle" for most ceramic sols or suspensions is a colloidal sol of hydrophilic clay or of alkaline silicates. Newer colloidal sols include hydrous aluminas and aluminum phosphate, zirconia, and such organometallic substances as the titanium and zirconium alkylates and methyl and ethyl silicates. Such colloidal sols are in some instances converted irreversibly to stable oxides by dehydration, hydrolysis, or vapor interactions. They may therefore be applied and "cured" at temperatures well below those which are necessary for more conventional ceramic coating techniques.

Adherence

Because a ceramic layer initially wets and conforms to a substrate does not insure that it will adhere. The "adherence" of a coating has been defined as the ability of the composite to withstand certain applied stress without separation or failure, and it is usually reported as the

*Submitted for publication January 11, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

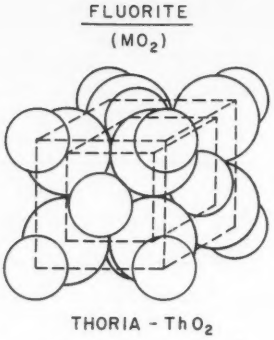


Figure 1—Structure of fluorite (MO_2)

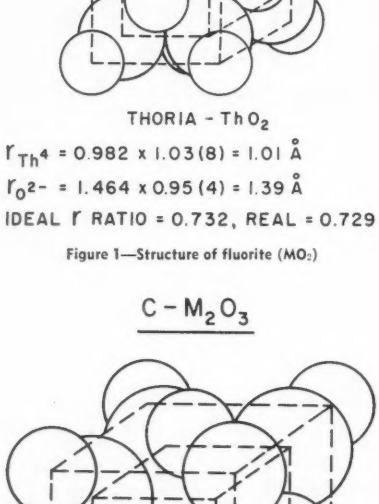


Figure 2—Structure of C-M_2O_3.

magnitude of stress which will just cause failure. Some adherence tests[4] are based upon measuring the area of coating which is retained after a given deformation of the composite has been produced. Data obtained in this way cannot be related to ultimate failure stresses.

It is an insufficient requirement that the ceramic coating adhere to the substrate when thermal protection is required. On copper in an oxidizing atmosphere, for instance, the peculiar planar structure of CuO formed by oxidation of the underlying Cu_2O produces an exfoliation which sharply reduces both thermal transfer and oxidation. The actual thermal flux to a copper substrate obtained with any heat source is thus strongly influenced by the atmosphere to which it is exposed. Since the exfoliated CuO layer is rather weakly adherent, its protective influence is sharply decreased when it is exposed to abrasive or highly erosive flow.

It is this requirement of coating *integrity* which makes adherence difficult to measure in a meaningful way. In most instances, it is sensible to resort to preliminary screening tests for a given coating-substrate combination. These must represent a realistic heat flux to a specimen of meaningful geometry. Unless they do, a given set of composite systems can be made to exhibit different orders of merit in different test equipment. In most instances, adherence can be evaluated only by service life tests, and the coating technologist must be aware that for some applications adherence may not be even a necessary requirement for satisfactory performance.

Protection

Employment of a coating tacitly assumes that the substrate material alone is unsuitable for its task. In the majority of instances it is the function of the coating to protect the substrate from heat and/or from interactions with the atmosphere at high temperatures.

Where protection against heat alone is needed, the coating must be insulative. A high degree of insulation at low temperatures often can be achieved simply by using a coating which is porous. At higher temperatures porous ceramic coatings tend to be relatively transparent to radiant heat, and the coating material must be fairly dense. At still higher temperatures a duplex coating (consisting of a refractory outer layer over an insulative lower layer) can be employed. For the highest temperature exposures the outer coating may be replaced by or overcoated with a material which ablates (melts or volatilizes in a controllable way) to reduce the heat absorbed.[5] It should be noted that there may be a positive disadvantage in the use of any of these coatings when they are exposed to higher (and in some instances, to lower) temperatures than those for which they are intended.

The most challenging areas for coating development at present are in the field of the "high-temperature elements"—niobium, tantalum, molybdenum, and tungsten and graphite. These metals and their alloys possess respectable strengths to above 1500 C in inert atmospheres, but rapidly oxidize in air. Coatings presently used to increase their service temperatures usually involve silicon (as a vapor-deposited coating, as a silicide of the metal, or as silicon carbide) or chromium, usually applied by pack diffusion methods.

The metals which are being protected from oxidation by their own oxide films are Be, Mg, Al, Si, Ta, Nb, Cr, Mn, Fe, Co, Ni, and Zn. In some instances the protective oxide film is ruptured by strong dissimilarities in expansion, and the metals which are most oxidation-resistant are Al, Si, Cr, Ni and their alloys.

In all cases, the most protective oxides are crystal structures in which the oxygen ions are closely packed, forming lines or chains in three dimensions. Such an arrangement occurs in the oxides having the quartz, corundum, spinel, and perovskite structures.[6] It is reasonable to believe that the three-dimensional extension of the oxygen ions not only restricts diffusion of oxygen atoms and molecules but also minimizes the magnitude of thermal vibrations which might lead to migration of the ions themselves.

Inasmuch as these structures are predictable on the basis of the size, valence, and number of their metal ions, it seems logical to suppose that they can be synthesized and applied to a variety of metal substrates, using such recently developed techniques as flame- or arc plasma-spraying, cataphoretic deposition, or colloidal attachment. The coated specimens could then be evaluated directly for oxidation resistance at several temperature levels.

This can be done only if unlimited funds are available. There are more than 24 possible oxide spinel compositions AB_2O_4 made from divalent and trivalent metal ions; spinels containing monovalent and hexavalent ions are known. The perovskite system ABO_3 may exist in nearly twenty combinations of metals whose valences total six. If these are multiplied by the wide choice of substrates, of substrate preparations, and methods of application, the immensity of the task will be appreciated.

Where the major role of the coating is to provide physical protection, the problem is not so great. Ceramic coatings which are very hard can be made with oxides and suboxides by flame-spraying. Where greater hardness is required, interstitial carbides and borides can be incorporated into the coating. Such abrasion-resistant coatings can protect the passive oxide films upon which all but the noble metals depend for resistance to chemical attack. Oddly enough, little interest has thus far been shown toward this application.

Thus far it has been the purpose of this presentation to describe in a general way, a philosophy of refractory ceramic coating technology. This philosophy can be illustrated by two specific coating tasks and methods by which they were attacked.

Illustrations of Coating Principles

Development of an Oxidation-Resistant Iron Alloy

As iron is thermally oxidized, it forms FeO at its surface. This oxide may be regarded as an iron-deficient lattice of close-packed oxygen ions with ferrous ions distributed in its octahedral voids. There is thus a smooth transition from Fe to FeO. Since the lattice of iron is congruent with that of close-packed oxygen, a coating of FeO adheres to iron.

FeO has, ideally, the rock-salt structure, but it is always deficient in iron. A unit cube of edge 8.6 a.u. containing 32 oxygen ions can accommodate 32 ferrous ions in its octahedral voids, and this would be the structure of stoichiometric FeO. Actually, FeO contains 32-X ferrous ions and 2X/3 ferric ions. If iron atoms continue to be removed (or as oxidation continues) until there are only 24 iron atoms, the compound magnetite, Fe_3O_4, is formed as a ferrite spinel. Iron can be continually removed until gamma-Fe_2O_3, with an average of 21⅓ iron atoms, all trivalent, are distributed in the lattice.

Further oxidation forms hematite, Fe_2O_3, with the corundum (hexagonal structure) which is not adherent.

The oxidation of iron, therefore, is controlled by the rate of diffusion of iron atoms into the several oxide layers. This diffusion can be stopped only by presenting, somewhere in the adherent portion of the coating, an effective barrier to the migration of iron. A plan of attack, therefore, is to alloy the iron with another metal which will act, upon oxidation, to form such a barrier layer—i.e., to develop an alloy whose oxide coating will not dissolve iron.

It is easy to show that no single metal will accomplish this; nickel must be present as more than half the structure before the migration of trivalent iron ceases. The use of both nickel and chromium in the familiar 18-8 percent proportions forms stainless steels from which iron migrates appreciably at 900 F.

It has been found that[7] Fe_2O_3 can enter the lattice of Al_2O_3 only to the extent of a few percent. The high oxidation potential of Al (1.66V) as compared with that of iron (0.44V) causes the reduction by Al of neighboring iron oxides to metallic iron, even when the aluminum is present in dilute solution. It follows that phases containing oxidized iron can co-exist only with substantially pure Fe until the temperature is reached at which the compound $Fe_2O_3 \cdot Al_2O_3$ is formed, about 2000 F.

Unfortunately, Al_2O_3 will dissolve almost 12 percent of Fe_2O_3. To repress solution, a metal is needed which will form with Al_2O_3 a solid solution in which Fe_2O_3 is insoluble. This metal, like Al, must have a higher oxidation potential than that of iron and must have a trivalent ion nearly equal in size to that of iron. Chromium, with an oxidation potential of 0.74V and a tripositive radius of 0.557 a.u. most nearly fits these requirements, and it conforms also to the requirement that its vapor pressure at all temperatures be lower than that of aluminum.

In consequence, the most oxidation-resistant ternary ferrous alloy will contain equimolar proportions of aluminum and chromium. The alloy finally developed for high-temperature electrical strain gage use[8] contained 70 percent iron, 20 percent chromium, and 10 percent aluminum, or $Fe_{70}Cr_{20}Al_{10}$.

The example cited here is not intended to suggest that the way to design a new alloy is to design its oxide film; in most instances this will merely produce an alloy which is unworkable. It is suggested, however, that present knowledge of crystal chemistry is sufficient to permit some "tailoring" of coatings for their specific purpose. The following illustration is selected as an example.

Development of an Oxidation Catalyst Coating[9]

The need for more efficient and complete combustion is paramount in internal combustion engines. Foundation scientists conceived the possibility of achieving it by applying a catalyst coating to the interior walls of a combustion chamber. It was hoped that such a coating would also be thermally insulative, refractory, and inert to ordinary poisoning agents encountered in combustion gases.

On the basis of purely theoretical reasons, certain of the rare earth oxides were selected as the most promising coating candidates. On the basis of cost, cerium oxide was the most logical choice. The catalytic behavior of ceria has been soundly demonstrated.

Cerium oxide exists at ordinary temperatures in the fluorite structure, shown in Figure 1 (the geometrical requirements for ion packing are for thorium oxide, which also crystallizes in this form).

At high temperatures, cerium oxide loses oxygen and becomes Ce_2O_3 with the structure shown in Figure 2. Comparison of the two structures shows that the oxygen ion lattice (an ion at each corner of the cube) is, in the c-M_2O_3 structure, lacking a corner ion, and the cerium ion adjacent to it is the larger tripositive ion.

The small adjustments in position required for converting CeO_2 to Ce_2O_3 suggests that at some intermediate temperature this material will act either to entrap or evolve oxygen, and will therefore be an effective oxidation catalyst. Unfortunately, this temperature is slightly above 1000 C, far too high for use, say, on a diesel engine piston.

In simple terms, this means that the c-M_2O_3 type of structure must be made stable at lower temperatures. This can be done by adding the oxide of a trivalent metal whose ion is larger than that of trivalent cerium. Lanthanum oxide, easily coprecipitated with ceria, is a logical choice.

Since the process of flame-spraying in itself provides rapid chilling from high temperatures, it was predicted and observed that flame-sprayed coatings[10] made from modified ceria would possess an unusual proportion of the c-M_2O_3 structure. Such coatings were found to be adherent and insulative on a variety of substrates.

The behavior of this coating in internal combustion engines is beyong the scope of this presentation. It is sufficient to note that its catalytic and thermally insulative properties have been confirmed. Trial coatings on railway diesel engines have achieved significant economies[11] and appear to be permanent.

Refractory coating technology is not new. There are, however, soundly based principles of solid-state physics, crystal chemistry, thermodynamics, stress analysis, and ceramic engineering which can augment the empirical methods usually applied to coating research.

References

1. W. D. Kingery. Kinetics of High-Temperature Processes. Wiley & Sons, N. Y. C. (1959).
2. Olive G. Engel. Pits in Metals Caused by Collision with Liquid Drops and Soft Metal Spheres. *J. Res. N. Bu. S.*, 62, 6, 229 (1959).
3. D. G. Moore. National Bu. Standards Report No. 5, Project 0904-11-09440 (1959).
4. PEI-T17. Porcelain Enamel Institute, Washington, D. C.
5. W. H. Steurer and H. C. Sullivan. Principles of Composites for Heat Absorption. Sixth Sagamore Ordnance Materials Research Conf., Syracuse Univ. (1959).
6. R. C. Evans. Introduction to Crystal Chemistry. Cambridge Press, London (1946).
7. L. M. Atlas and W. K. Sumida. Solidus, Subsolidus, and Subdissociation Phase Equilibria in the System Fe-Al-O. *J. Am. Cer. Soc.*, 41, 150, 5, (1958).
8. Development of High-Temperature Electrical Strain Gage Alloy. Research project for Naval Air Material Center, Philadelphia, Pa.
9. "Catalyst Coatings" *Frontier* (Armour Research Foundation). Winter (1957).
10. U. S. Patent No. 2,904,449.
11. R. A. Bardwell. *Modern Railroads* (1959) Mar.

Any discussion of this article not published above will appear in December,, 1960 issue.

Reaction Velocity in the Corrosion of Iron By Hydrogen Sulfide and the Effect of Inhibitors*

By GEORGE S. GARDNER

Abstract

The rate of reaction of iron and hydrogen sulfide has been studied in an oxygen-free system in the presence of sodium chloride brine, in the presence and absence of an oil phase under a constant mixing rate at 40 C and 80 C.

The experimental data are plotted according to a previously derived equation for the iron-acetic acid system, and are shown to be in agreement with that equation. Values of K, the overall reaction velocity, are obtained from the slopes. From the K values for three sets of experiments at 40 C and 80 C, values for the temperature coefficient

$$\frac{K_{T+10}}{K_T} = a,$$

are calculated, and are shown to correspond to the range of values expected for diffusional control. The presence of an oil phase seems to have little influence on the reaction rate.

Another group of measurements on the iron-hydrogen sulfide system was carried out in the presence of corrosion inhibitors. While all the data of the inhibited reactions will show reasonable straight line plots, when plotted according to the diffusional equation, such plots have little meaning with the good inhibitors, because there is no essential change with time in the loss-in-weight values when they are used at 50 ppm. There seems to be some possibility that good inhibitors function by forming a particularly efficient non-permeable adsorbed film with iron sulfide corrosion products. 6.2.2

About the Author

GEORGE S. GARDNER, research chemist with Amchem Products Inc., Ambler, Pa., is the author of research papers on heterogeneous reactions and corrosion phenomena, and has been granted several patents on corrosion inhibitors. He is a member of NACE, Franklin Institute, API, AAAS, ACS and a Fellow of the American Institute of Chemists.

Kinetics of Corrosion Reactions

THE CORROSION of iron and its alloys by aqueous solutions of hydrogen sulfide in the absence of oxygen can be most simply visualized as the formation of solid iron sulfide, without any further assumptions as to the exact nature of this iron sulfide. It is thus an example of a heterogeneous reaction between a solid and a liquid, in which the products of the reaction are another solid (iron sulfide) and a gas (hydrogen). It can be seen that the kinetics of this reaction might involve the following possibilities (Figure 1):

(a) If the actual rate of reaction of iron and hydrogen sulfide at the phase boundary is more rapid than the rate of transport of hydrogen sulfide to the iron surface, the reaction can be controlled by the rate of diffusion of hydrogen sulfide through the iron sulfide layer, providing that this sulfide layer is intact, and not removed from the surface.

(b) If the actual rate of reaction of iron and hydrogen sulfide at the phase boundary is more rapid than the rate of diffusion of hydrogen sulfide to the iron surface, but the iron sulfide layer is removed from the surface as it is formed, the reaction rate can be related to the rate of diffusion of hydrogen sulfide through the "Nernst film" of liquid on the metal surface.

(c) If the actual rate of reaction of iron and hydrogen sulfide at the phase boundary is slower than the rate of diffusion of hydrogen sulfide to the iron surface, the reaction rate is then controlled by the activation energy in the reaction between iron and hydrogen sulfide.

According to the investigations of Fick,[1] Noyes and Whitney,[2] and Nernst and Brunner,[3] and based on some recent work carried out by other investigators,[4,5] possibilities (a) and (b) can be expressed by the equation:

$$-\frac{dm}{dt} = A\left(\frac{D}{r_1 + r_2}\right)\left(\frac{m}{V}\right). \qquad (1)$$

Similarly, the rate of the activation-controlled reaction (c) would be expressed by the equation:

$$-\frac{dm}{dt} = A\,K_{act.}\left(\frac{m}{V}\right)^n \qquad (2)$$

In the above equations m is the number of gram-moles of reactant present at time t in the solution, A is the area of the reacting surface (the phase boundary), r_1 is the diffusional resistance offered by the Nernst film,[3] r_2 is the diffusional resistance offered by the layer of reaction product, K_{act} is the velocity constant of the activation-controlled reaction, and t is the elapsed time from the beginning of the experiment. In an activation-controlled reaction the exponent n can vary from 0 to 2.

It can be seen from the form of equations (1) and (2) that it is not possible to distinguish diffusion-controlled and activation-controlled reactions solely on the basis of data inserted into these equations, and that other considerations must enter into the picture. Some of the criteria used to distinguish between these two types of reaction are the following:

Diffusion-controlled reactions: The velocity of agitation affects the rate of reactions of type (b) by changing the thickness of the Nernst film, thus changing the rate of diffusion. Another very useful criterion is the temperature coefficient of reaction, which is usually low for diffusion-controlled reactions.

Activation-controlled reactions: The value of the rate constant is not changed by the rate of stirring; and, as noted above, the temperature coefficient of the reaction is markedly higher than for diffusion-controlled reactions.

Although the variation with rate of stirring has been used successfully[6] for determining the type of control involved in a given reaction, the variation of the rate constant with temperature seems to be the most useful in the present instance.

Taylor,[7] expressing the temperature coefficient of reaction velocity as the ratio of K values for a 10C temperature difference,

$$\frac{K_{T+10}}{K_T},$$

shows that the early work of Öholm on the change of diffusion rate with temperature in liquid systems can be expressed as

$$\frac{D_{T+10}}{D_T} = 1.20 \text{ to } 1.48,$$

and that this range of values for the temperature coefficient of diffusion is

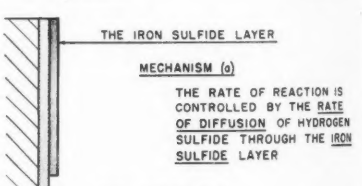

THE IRON SULFIDE LAYER
MECHANISM (a)
THE RATE OF REACTION IS CONTROLLED BY THE RATE OF DIFFUSION OF HYDROGEN SULFIDE THROUGH THE IRON SULFIDE LAYER
THE NERNST FILM
MECHANISM (b)
THE RATE OF REACTION IS CONTROLLED BY THE RATE OF DIFFUSION OF HYDROGEN SULFIDE THROUGH THE NERNST FILM
THE METAL SURFACE
MECHANISM (c)
THE ACTIVATION ENERGY OF THE REACTION IS THE CONTROLLING FACTOR

Figure 1—Schematic representation of the possible factors affecting the reaction between iron and hydrogen sulfide.

★Submitted for publication October 5, 1959. A paper presented at a meeting of the Northeast Region, National Association of Corrosion Engineers, Baltimore, Maryland, October 5-8, 1959.

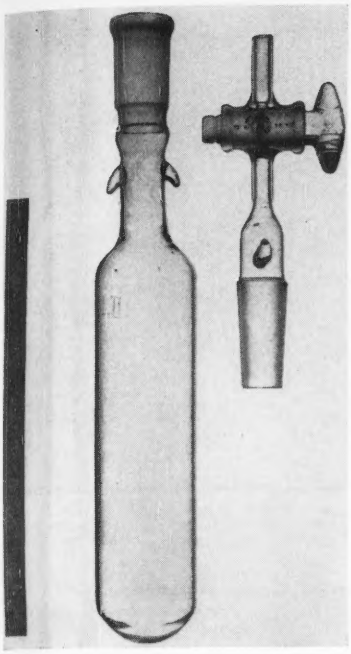


Figure 2—Reaction vessel for use at 40 C.

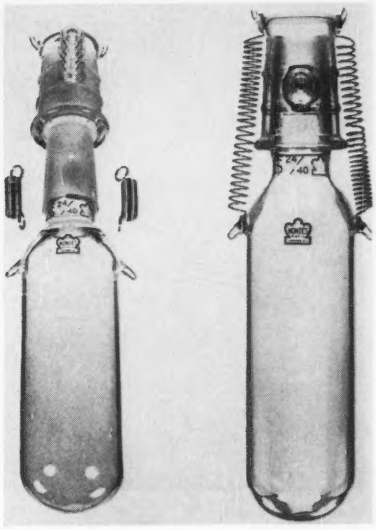


Figure 3—Experimental reaction vessel for use at 80 C.

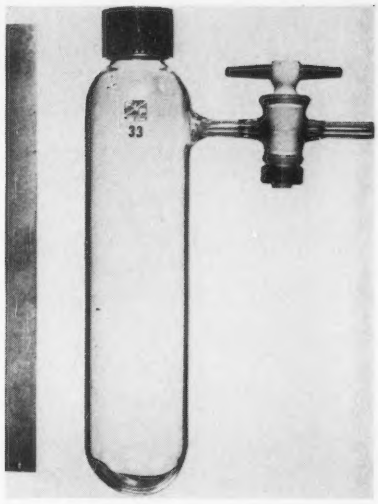


Figure 4—Preferred form of reaction vessel for use at 80 C.

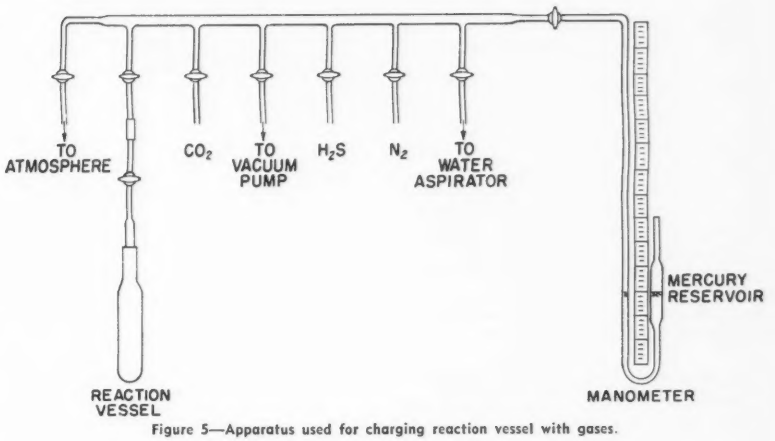


Figure 5—Apparatus used for charging reaction vessel with gases.

similar to those obtained for the temperature coefficients in diffusion-controlled reaction systems, gaseous systems giving the lower values, and liquid systems showing the higher values. On the other hand, high temperature coefficients indicate the chemical processes at work as the factors determining the reaction rate. Homogeneous reaction coefficients show a variation of from 1.82 to 4.13, the value rarely dropping below 1.82.

Experimental Procedures

Most reaction velocity studies have been made in homogeneous systems. This comes about no doubt because of the difficulty of experimentation in heterogeneous systems, and the further difficulty of interpretation of results when they are obtained. In addition to this, the majority of investigations in heterogeneous systems have been carried out on catalysts, and particularly on catalysts for technical gas reactions.

The problem was to design a system for the study of reaction between a metal and a liquid corrodent. There was, of course, the usual choice between a static and a dynamic system. In this connection a static system is defined as one in which neither reactants nor products leave the system, although the system can be in motion—stirred, tumbled, etc.

A dynamic system is usually thought of as a flowing system, in which fresh reactant is continually brought into the system. While either type of system might be used to study the reaction between iron and hydrogen sulfide, the static system had been used in previous work[4] and therefore was applied in the present instance.

Since the apparatus used has been described elsewhere,[4] only a brief description will be given here. The essential parts are:

(1) The reaction vessel;
(2) The manometer-manifold system;
(3) The heating cabinet.

Three different types of reaction vessels have been used, as shown in Figures 2, 3, and 4. All three types have a capacity of approximately 140 ml. The vessel shown in Figure 2, the original testing vessel as used for corrosion tests, has been very satisfactory for work at 40 C, and is still in regular use for that purpose. The vessel in Figure 3 was designed for work at 80 C. This vessel has not been entirely satisfactory, however, some leakage occurring at the large joint. The vessel shown in Figure 4 is the most satisfactory developed to date. The stopcock is Teflon, adjustable as to pressure, and the top is plastic, containing a soft neoprene gasket. This vessel is used entirely for work at 80 C.

The heating cabinets used in the experiments, Figure 6 for reactions at 40 C and Figure 7 for reactions at 80 C, are thermostatically controlled, with fan-induced air circulation. They permit turning the reaction vessels end-over-end at a rate of 15 rpm.

In carrying out velocity experiments in the iron-hydrogen sulfide system, the steel strip, of SAE 1010 hot-rolled steel, 0.5 in., x 7 in., x 0.030 in., is first cleaned in hydrochloric acid containing no inhibitor, rinsed in water and alcohol, dried, and weighed. The strip is placed in the reaction vessel, the liquid phases added, and the vessel is evacuated on the manometer-manifold system, Figure 5. After flushing with nitrogen four times, the vessel is evacuated and hydrogen sulfide is introduced to the proper pressure, determined by the number of milligrams of hydrogen sulfide desired in the experiment. Nitrogen is then admitted to a pressure slightly above atmospheric, the vessel is closed, and placed in the heating cabinet for the required period. At the expiration of the reaction period the metal strip is removed, immersed in strongly inhibited hydrochloric acid,

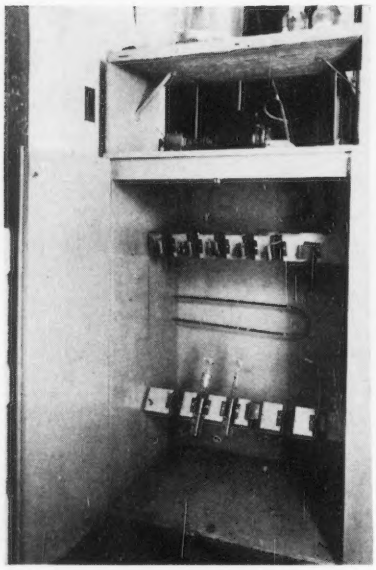


Figure 6—Heating cabinet for use at 40 C.

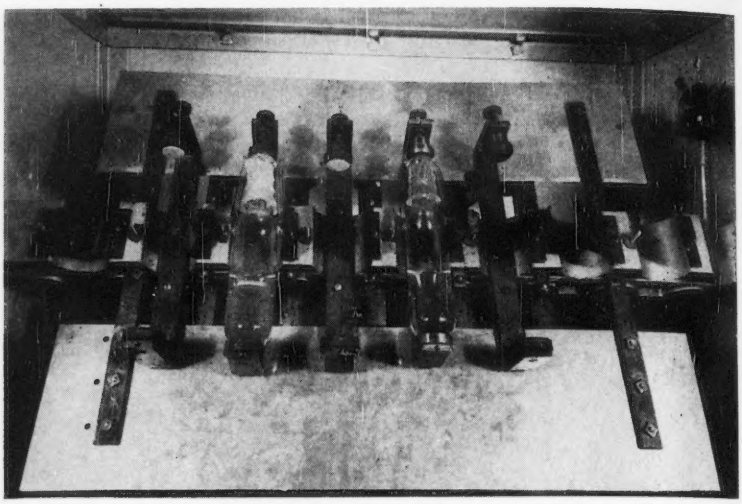


Figure 7—Heating cabinet for use at 80 C.

scrubbed with detergent, rinsed in water and alcohol, dried, and reweighed.

Experiments in the Absence of Inhibitors

In Table 1 are given data on six series of experiments designed to study the course of the reaction between iron and hydrogen sulfide in the absence of inhibitors. The reaction vessel contained only brine, mineral spirits (in two cases the mineral spirits was omitted), hydrogen sulfide, nitrogen, and the steel strip. No added corrosion inhibitor was present in any of these six experiments. Each single measurement refers to an entirely new run—with a new strip of steel.

Experiments in the Presence of Inhibitors

Fifteen experiments were carried out on the reaction between iron and hydrogen sulfide, using exactly the same technique as above, but with corrosion inhibitors placed in the liquid phase. The inhibitors were varied as to kind and amount. The inhibitors used were:

Inhibitor "A"*: An oil-soluble inhibitor, designed for refinery and sour well corrosion inhibition.

Inhibitor "B": An oil field sour well inhibitor; oil soluble.

Inhibitor "C": An oil field inhibitor; oil soluble.

Inhibitor "D": An acid inhibitor, not specifically designed for hydrogen sulfide inhibition.

Inhibitor "E"*: A water-soluble, brine dispersible, inhibitor, effective in hydrogen sulfide, hydrochloric acid, and oxygen corrosion.

The results of these experiments are shown in Tables 2, 3, and 4.

Velocity in the Reaction between Iron and Hydrogen Sulfide in the Absence of Inhibitors

If equation (1) is modified by putting $r_2 = 0$, which is to say that the layer of

* Inhibitors A and E are "Rodines"R, products of Amchem Products, Inc.

TABLE 1—Loss-in-weight Data in the Absence of Inhibitors

Temp., °C	40	40	40	80	80	80
4% NaCl brine	30 ml.	30 ml.	60 ml.	30 ml.	30 ml.	60 ml.
Mineral spirits	30 ml.	30 ml.	none	30 ml.	30 ml.	none
H_2S, ppm of brine	1000	2000	1000	1000	2000	1000
Time in Hours	**Loss in wt, mg**					
1	.....	.....	.....	7.4, 7.6	13.0	7.5, 7.5
2	4.6, 4.6	5.0, 4.7	5.8, 5.2	12.9, 12.5	23.5	19.1, 17.7
3	.....	.....	.....	17.4, 18.2	32.1	27.2, 26.5
4	6.6, 6.7	8.1, 8.8	8.8, 9.3	21.8, 22.2	39.1	35.4, 37.7
7	9.0, 9.6	12.5, 12.5	17.5, 18.6	32.3, 32.5	....	54.8, 55.8
8	.....	.....	.....	.....	62.2	.....
16	21.4, 18.1, 17.8	25.6, 25.9	32.4, 30.0	43.8, 43.4	82.5	83.7, 85.8
20	23.3, 25.7	30.2, 30.4	44.3, 39.2	.....	....	.....
24	29.8, 30.6	37.5, 34.7	43.1, 44.0, 45.6	45.7, 45.6	....	85.6, 88.3
30	32.0, 30.5	44.6, 43.6	53.0, 52.0	.....	....	.....
40	39.3, 38.2	52.9, 56.9	63.3, 60.9	.....	....	.....
48	42.0, 41.9	63.1, 65.4	71.6, 71.8	.....	....	92.1, 89.7
72	.....	77.8, 78.1	83.8, 88.2	.....	....	.....
96	.....	.....	92.3, 90.7	.....	....	.....

TABLE 2—Loss-in-weight Data in the Presence of Inhibitors

Temp., °C	80	80	80	80	80	80
4% NaCl brine	30 ml.	30 ml.	30 ml.	30 ml.	30 ml.	30 ml.
Mineral spirits	30 ml.	30 ml.	30 ml.	30 ml.	30 ml.	30 ml.
H_2S, ppm of brine	2000	2000	2000	2000	2000	2000
Inhibitor	A	A	A	B	B	B
Inhibitor conc., ppm of brine	20	30	50	20	30	50
Time in Hours	**Loss in wt, mg**					
4	8.0, 5.2	6.1, 5.8	.....	17.2, 9.6	6.9, 6.7	.....
6	.....	.....	5.7, 4.0	.....	.....	4.5, 4.8
7	5.7, 6.0	6.7, 6.7	.....	15.8, 9.8	6.9, 6.9	.....
16	16.1, 6.9	6.5, 5.7	6.4, 7.5	19.6, 11.8	6.7, 6.7	6.5, 4.4
24	9.9, 8.5	6.6, 6.6	5.8, 5.3	14.2, 17.2	7.1, 6.9	5.8, 5.2
48	11.4, 16.8	6.8, 5.6	6.2, 7.1	42.7, 43.6	19.1, 8.6	6.8, 4.0
72	10.3, 8.1	6.9, 6.8	7.5, 6.4	14.3, 41.4	5.5, 7.5	6.3, 6.7
96	59.8, 16.0	8.4, 7.8	.....	56.6, 77.5	8.1, 11.1	.....

TABLE 3—Loss-in-weight Data in the Presence of Inhibitors

Temp., °C	80	80	80	80	80
4% NaCl brine	30 ml.	30 ml.	30 ml.	30 ml.	30 ml.
Mineral spirits	30 ml.	30 ml.	30 ml.	30 ml.	30 ml.
H_2S, ppm of brine	2000	2000	2000	1000	1000
Inhibitor	C	D	E	B	E
Inhibitor conc., ppm of brine	50	50	50	50	50
Time in Hours	**Loss in wt, mg.**				
6	41.1, 39.1	10.7, 11.6	6.8, 4.7	5.3, 4.2	5.2, 5.3
16	79.5, 78.6	15.7, 19.4	10.8, 10.6	5.1, 4.9	.....
24	86.8, 89.8	23.3, 22.1	8.4, 9.7	7.4, 7.7	7.7, 9.0
48	94.4, 93.9	31.5, 39.0	9.1, 7.8	6.8, 6.7	6.5, 8.7
72	89.9, 95.1	21.4, 40.9	7.5, 6.7	7.0	10.3, 11.3

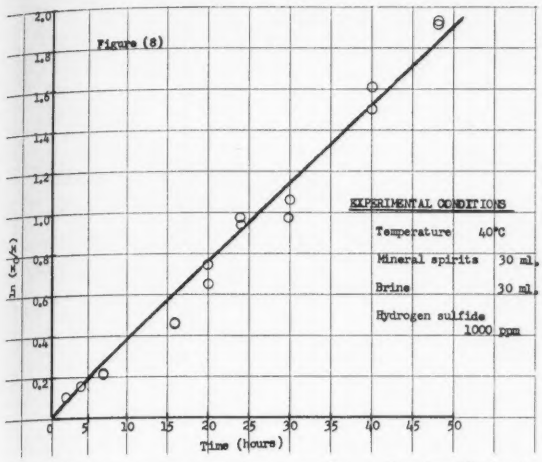


Figure 8—Plots of $\ln(x_0/x)$ versus time, according to Equation (4) for the reaction between hydrogen sulfide and iron in the absence of inhibitors (data of Table 1). Hydrogen sulfide content was 1000 ppm.

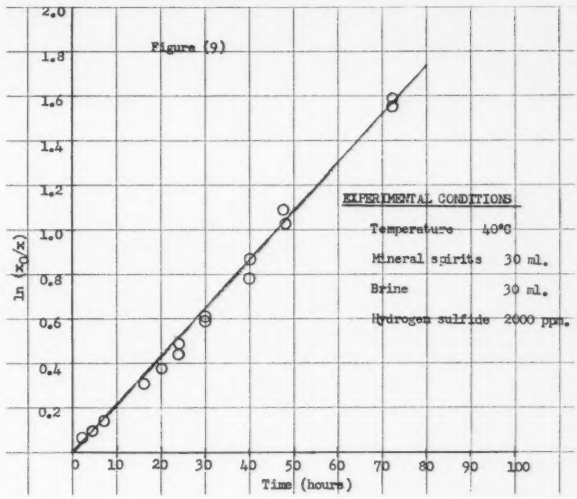


Figure 9—Reaction between hydrogen sulfide and iron in the absence of inhibitors (data of Table 1). Hydrogen sulfide content was 2000 ppm.

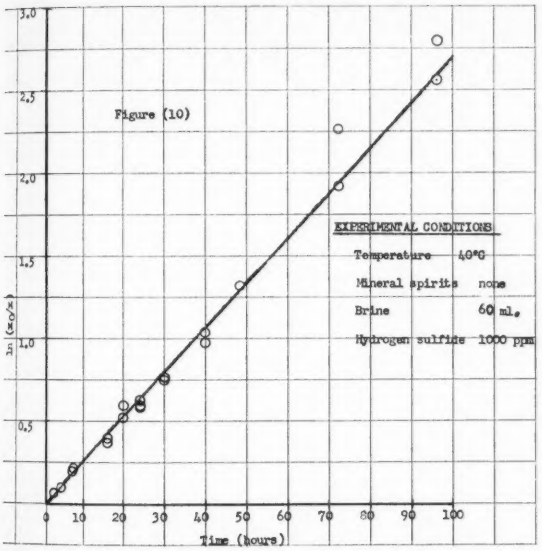


Figure 10—Reaction between hydrogen sulfide and iron in the absence of inhibitors (data of Table 1). No mineral spirits used.

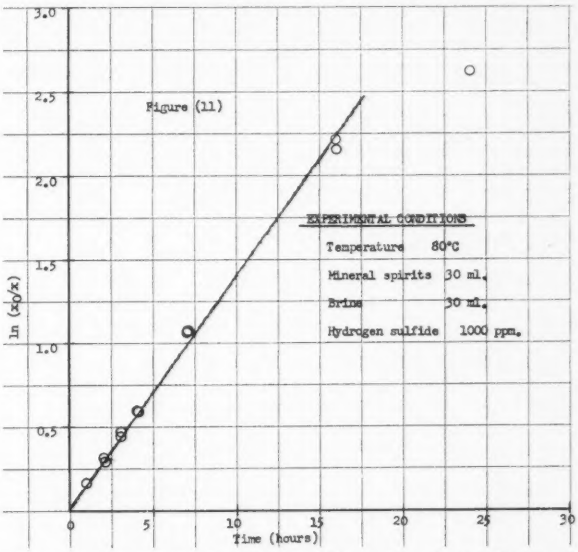


Figure 11—Reaction between hydrogen sulfide and iron in the absence of inhibitors (data of Table 1). Thirty ml of mineral spirits used.

iron sulfide reaction product has no significant effect on the diffusion rate, the equation can be rewritten as: (5)

$$-dx/dt = (1 - s)\ (AD/hV)\ (x), \quad (3)$$

where,

D = the diffusion coefficient,
x = mg. of reactant in the solution at time t,
t = time in hours, measured from the beginning of the experiment,
s = fraction of the solid surface covered by adsorbed inhibitor,
h = thickness of the Nernst liquid film,
A = area of the metal surface, cm^2,
V = volume of the aqueous phase, cm^3,
w = weight loss of the metal at time t, in mg.

TABLE 4—Loss-in-weight Data in the Presence of Inhibitors

Temp., °C.	40	40	40	40
4% NaCl brine	30 ml.	30 ml.	30 ml.	30 ml.
Mineral spirits	30 ml.	30 ml.	30 ml.	30 ml.
H_2S, ppm. of brine	1000	1000	1000	1000
Inhibitor	B	C	D	E
Inhibitor conc., ppm. of brine	50	50	50	50
Time in Hours	**Loss in wt, mg.**			
7	2.2, 2.4	.....	1.8, 3.4	2.5, 3.0
16	2.5, 2.5	22.5, 22.8	8.5, 8.6	4.2, 3.2
20	2.5, 1.8	25.1, 26.7	.....	4.3, 4.4
24	2.5, 3.8	29.8, 27.6	7.8, 7.4	6.5, 4.7
40	.....	37.4, 39.7	.....	.....
48	3.6, 3.5	.....	18.7, 21.2	4.9, 3.3
72	2.1, 3.8	.....	30.1, 24.6	4.8, 4.6

Integrating (3), with $x = x_0$, when $t = 0$,

$$(1 - s)(AD/hV) = \ln(x_0/x)/t = K, \quad (4)$$

where K is the over-all apparent reaction velocity constant, representing the group $(1 - s)(AD/hV)$, and can be obtained as the slope when $\ln(x_0/x)$ is plotted against t.

The values for the group $\ln(x_0/x)$ have been calculated for all the experiments shown in Table 1, a sample calculation of the data being shown in Table 5 for one series of experiments. All the

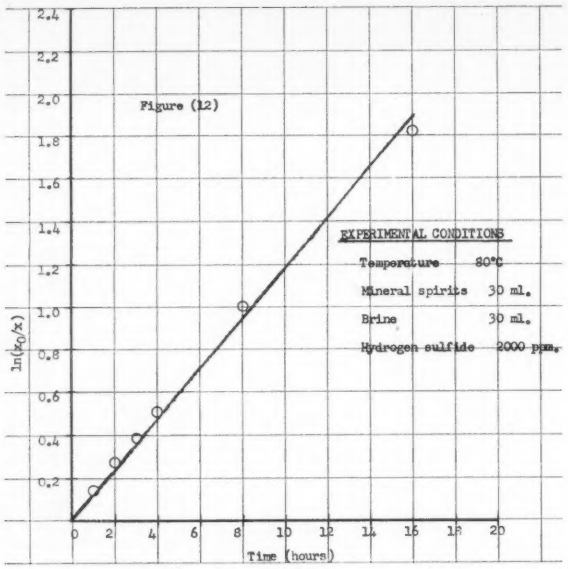


Figure 12—Reaction between hydrogen sulfide and iron in the absence of inhibitors (data of Table 1). Hydrogen sulfide content was 2000 ppm; 30 ml mineral spirits used.

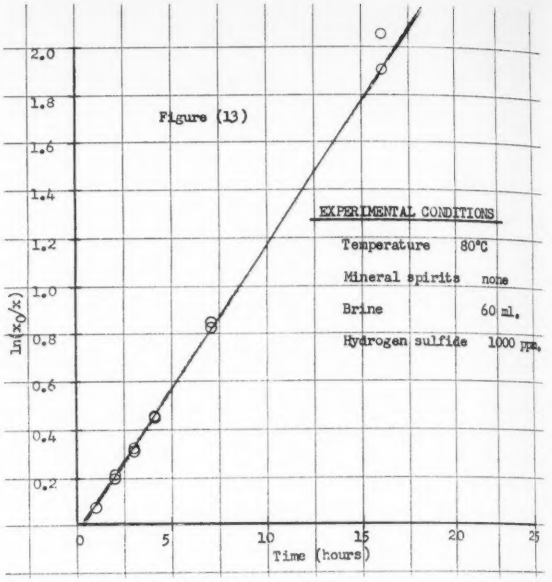


Figure 13—Reaction between hydrogen sulfide and iron in the absence of inhibitors (data of Table 1). Hydrogen sulfide content was 1000 ppm; no mineral spirits used.

values of $\ln(x_0/x)$ have been plotted against reaction time for all six experiments, and are shown in Figures 8 through 13. Allowing for a normal deviation in experimental data, all the plots are straight lines. From these plots the values of K were obtained as the slopes, and are shown in Table 6.

Several conclusions can be drawn from these data:

(1) Increasing thickness of the iron sulfide layer is not an important element in the course of the reaction, since equation (3) would not hold if this were the case, the more complete equation (1) being required. (For cases where the increasing thickness of reaction product is controlling, see Reference 8.)

(2) The K values indicate that the presence or absence of an oil phase is not a considerable influence on the reaction rate in the uninhibited systems.

Temperature Coefficient of Uninhibited Reaction

Using a previous definition of the temperature coefficient, the relation between the velocity constants at 40 C and 80 C can be expressed as $K_{40}\alpha^4 = K_{80}$. Thus, with the data of Table 6 on the values of K for 40 C and 80 C, it is possible to calculate values of α, the temperature coefficient.

As can be seen, the data of Table 6 fall into three sets, of two experiments each:

Set No. 1 is the pair represented by the data of Table 1, column 2 and 5, each experiment containing 1000 ppm of H_2S, and each containing both mineral spirits and brine. Since $K_{40} = 0.038$ and $K_{80} = 0.140$, $\alpha = 1.39$.

Set No. 2 is the pair represented by the data of Table 1, columns 3 and 6, each experiment containing 2000 ppm of H_2S, and each containing both mineral spirits and brine. Since $K_{40} = 0.022$ and $K_{80} = 0.118$, $\alpha = 1.53$.

Set No. 3 is the pair represented by the data of Table 1, columns 4 and 7, each experiment containing 1000 ppm of H_2S, and each containing brine as the liquid phase, with no mineral spirits. Since $K_{40} = 0.027$ and $K_{80} = 0.118$, $\alpha = 1.45$.

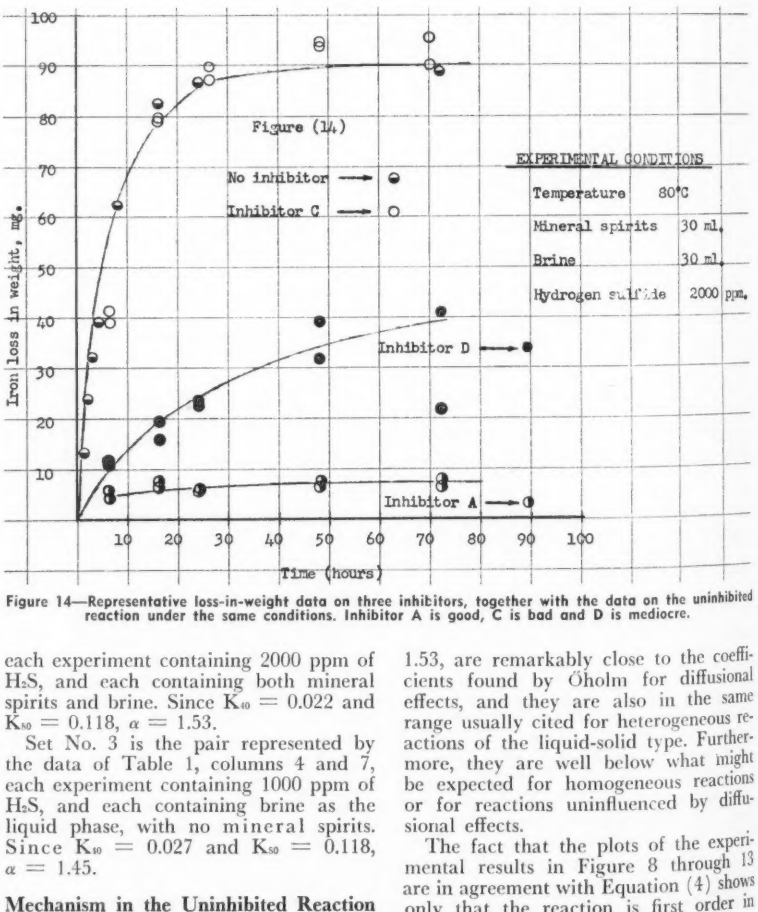


Figure 14—Representative loss-in-weight data on three inhibitors, together with the data on the uninhibited reaction under the same conditions. Inhibitor A is good, C is bad and D is mediocre.

Mechanism in the Uninhibited Reaction Between Iron and Hydrogen Sulfide

The coefficients α found for the iron-hydrogen sulfide reaction, 1.39, 1.45, and 1.53, are remarkably close to the coefficients found by Öholm for diffusional effects, and they are also in the same range usually cited for heterogeneous reactions of the liquid-solid type. Furthermore, they are well below what might be expected for homogeneous reactions or for reactions uninfluenced by diffusional effects.

The fact that the plots of the experimental results in Figure 8 through 13 are in agreement with Equation (4) shows only that the reaction is first order in nature, and does not distinguish between diffusional and activational control. The value of the temperature coefficients,

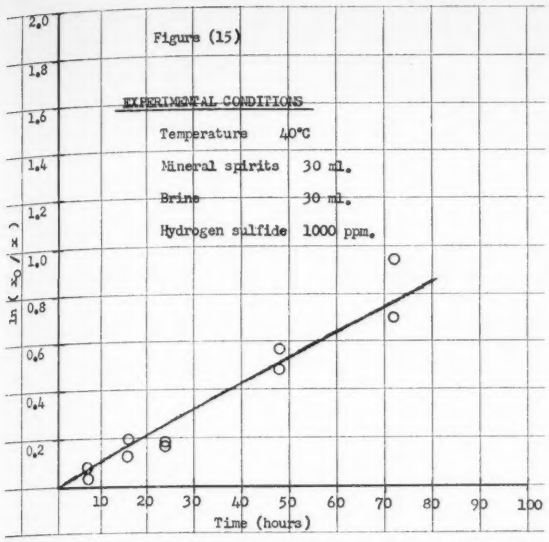


Figure 15—Plot of $\ln(x_o/x)$ versus time, according to Equation (4), for the reaction between hydrogen sulfide and iron in the presence of Inhibitor D, at 40 C.

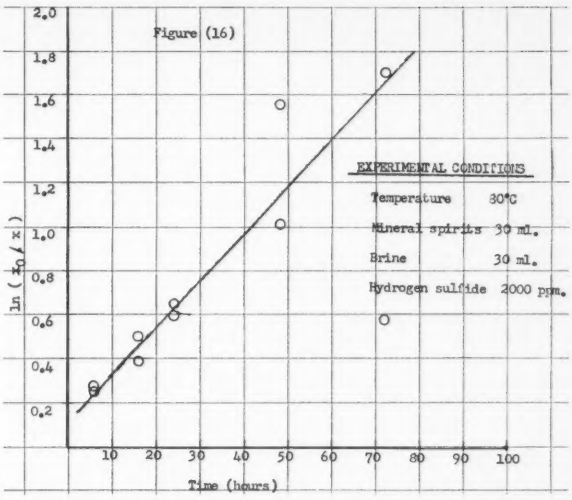


Figure 16—Plot of $\ln(x_o/x)$ versus time, according to Equation (4), for the reaction between sulfide and iron in the presence of inhibitor D, at 80 C.

TABLE 5—Tabulation Showing Sample Calculation of Data from Table 1 for Insertion in Equation (4)

Time in Hours, (t)	Loss in Wt., mg., (w)	(x_o-x)	x	x_o/x	$\ln (x_o/x)$
1.....	13.0	7.93	52.1	1.15	0.140
2.....	23.5	14.32	45.7	1.31	0.270
3.....	32.1	19.55	40.5	1.48	0.392
4.....	39.1	23.80	36.2	1.66	0.507
8.....	62.2	37.90	22.1	2.71	0.997
16.....	82.5	50.30	9.7	6.18	1.82

Temp. 80 C.
4% NaCl brine, 30 ml.
Mineral spirits, 30 ml.
H_2S = 60 mg. = x_o = 2000 ppm H_2S, based on the brine solution.

TABLE 6—Overall Reaction Velocity Constant K for the Uninhibited Reaction Between Iron and Hydrogen Sulfide

Figure	Mineral Spirits	Brine	Hydrogen Sulfide, ppm of Brine	Temp, Degrees C	K
8....	30 ml.	30 ml.	1000	40	0.038
9....	30 ml.	30 ml.	2000	40	0.022
10....	none	60 ml.	1000	40	0.027
11....	30 ml.	30 ml.	1000	80	0.140
12....	30 ml.	30 ml.	2000	80	0.118
13....	none	60 ml.	1000	80	0.118

however, points strongly toward diffusional control, and suggests that Equation (4) expresses the mechanism of the iron-hydrogen sulfide reaction under the experimental conditions. This finding was certainly not predictable, since it is not difficult to point out a number of corrosion reactions that are quite possibly under activational control.

Behavior of Inhibitors in Iron-Hydrogen Sulfide System

A careful examination of the experimental data on the reaction between iron and hydrogen sulfide in the presence of inhibitors, in Tables 2, 3, and 4, seems to indicate a remarkable change in the reaction mechanism when inhibitors are present in the solution. Considering, for example, the data on inhibitor "A," in Table 2, the remarkable fact is that these loss-in-weight quantities do not increase with time, either at 50 or 30 ppm of inhibitor. The results for the same inhibitor, at 20 ppm show considerable scatter, indicating that the film is probably no longer continuous.

The same type of behavior is shown for inhibitor "B." At 50 ppm, there is no essential change in weight loss from 6 to 72 hours. The results at 30 ppm are essentially the same, with some indication of increasing weight losses. Again, the results at 20 ppm show a considerable rise, but the increase is greater than with inhibitor "A." Here there might be a means for distinguishing between two inhibitors that are essentially good inhibitors.

Considering now Table 3, in which data on inhibitors B, C, D, and E are given, at 2000 ppm H_2S, the results are quite different from those for inhibitors A and B. Inhibitor C, at 50 ppm, is shown to give no inhibition at all, the loss-in-weight values being the same as the uninhibited experiment under the same conditions (see Table 1). Inhibitor D is somewhat intermediate in behavior, the loss-in-weight values showing a tendency to increase with time. Inhibitor E, however, now shows behavior quite similar to A and B. Summarizing these results, then, it can be said that A, B, and E are excellent inhibitors under these conditions, D is not particularly good, and that inhibitor C is completely ineffective.

All the data given in Tables 2 and 3 refer to 80 C. In Table 4 there is a change in conditions—the temperature is lowered to 40 C. The same phenomena are evident, however, at this lower temperature. Inhibitors B and E, which showed little change in loss-in-weight values with time at 80 C, still show that behavior at 40 C. Inhibitor D, which showed a tendency toward higher loss-in-weight values with increase in time, at 80 C, still shows that same tendency at 40 C. Inhibitor C, which showed no inhibition at all at 80 C, again shows the same behavior at 40 C.

Influence of Inhibitors on the Mechanism of the Iron-Hydrogen Sulfide Reaction

A previous investigation of the reaction between iron and acetic acid[9] has shown that there is no essential change in mechanism between the uninhibited and the inhibited reactions. A plot of the data on the iron-acetic acid reaction according to Equation (4) gave a straight line in the presence or absence of inhibitors, but with a change in slope—corresponding to a change in the value of $(1-s)(AD/hW)$—which permitted the calculation of the value of s, the fractional surface covered by adsorbed inhibitor for the iron-acetic acid reaction.

At first glance, relations would seem to be somewhat different in the iron-hydrogen sulfide inhibited system. In the presence of the good inhibitors, A, B, and E, at sufficient concentrations, there is little change in the loss-in-weight values with time, implying that one might be dealing with a zero order reaction,

$$-dx/dt = Kx^0,$$

in which K is close to zero. However, there is some evidence that this is not the case.

In Figure 14 representative data have been plotted for three inhibitors, A, C and D, (good, bad and mediocre inhibitors). Also plotted are the data on the uninhibited reaction, for the reaction at 80 C at 2000 ppm of hydrogen sulfide, in the presence of brine and mineral spirits. Examination of these curves suggests that the reaction might still be diffusional in the presence of inhibitors, and might proceed according to Equation (4), the value of s being close to zero for the case of inhibitor C, and close to 1.0 for the case of Inhibitor A.

If the experimental data of these different inhibitors are related to Equation (4), the following things are found:

The data on Inhibitor C will, of course, plot a straight line according to Equation (4), since its curve is the same as the curve of the uninhibited reaction, Figure 12.

The data on Inhibitor A will plot a straight line according to Equation (4), but the results have little meaning since the values are all the same—there is no change with time.

It is the data on Inhibitor D that are most revealing. There are two series of experiments on Inhibitor D, one at 40 C, and one at 80 C. These results are plotted in Figures 15 and 16. Although several of the experimental points are scattered, there seems to be little doubt that the mechanism is expressed by Equation (4).

Although the poor and mediocre inhibitors seem to follow a diffusional mechanism, this cannot necessarily be extrapolated to the good inhibitors. With these good inhibitors there could be a slower process than diffusion which would be controlling. One question that arises is, why are the good inhibitors so efficient? Is the initial formation of iron sulfide actually followed by the formation of a layer in which iron sulfide and inhibitor combine to form a particularly efficient non-permeable adsorbed film? The answer to this question might make possible a new approach to some corrosion inhibiting problems.

Acknowledgments

The author wishes to express his appreciation to his associates for their valuable comments, and particularly to Edgar S. Hayman for his conscientious skill in performing the experimental work.

References

1. Adolf Fick. "Uber Diffusion," *Pogg. Ann.*, 94, 59 (1855).
2. A. A. Noyes and W. R. Whitney. Uber die Auflösungsgeschwindigkeit von festen Stoffen in ihren eigenen Losungen. *Z. Phys. Chem.*, 23, 689 (1897).
3. W. Nernst. Theorie der Reaktionsgeschwindigkeit in heterogenen Systemen. *Z. Phys. Chem.*, **47**, 52, (1904); Erich Brunner, *ibid*, 56 (1904).
4. Gardner, Faigen, Gibson, and Hall. Researches on Corrosion and Inhibition; Reaction Velocity in the System Iron: Dilute Acetic Acid at 40 C. *J. Frank. Inst.*, **262**, 369-384 (1956).
5. Gardner, Faigen, Gibson, and Hall. *Ibid.*, 262, 469-478 (1956).
6. Cecil V. King. Reaction rates at Solid-Liquid Interfaces. *J. Am. Chem. Soc.*, **57**, 828 (1935).
7. H. S. Taylor. Treatise on Physical Chemistry. (Vol. II, 2nd ed.) McGraw-Hill Book Company, New York, 1936, p. 1026.
8. George S. Gardner. Reaction Velocity in the System: Solid I + Gas Solid II. *J. Math. Phys.*, **14**, 241 (1935).
9. George S. Gardner. Researches on Corrosion and Inhibition. Adsorption, Inhibition, and the Langmuir Equation. *J. Frank. Inst.*, **263**, 523-535 (1957).

Any discussion of this article not published above will appear in December, 1960 issue.

NATIONAL ASSOCIATION of CORROSION ENGINEERS

Qualified Approval for D-319 Analysis Austenitic Chromium-Nickel-Molybdenum Stainless Steel

NACE TECHNICAL COMMITTEE REPORT

Publication 60—10

A Report of NACE Technical Unit Committee T-5A*
On Corrosion in Chemical Processes

Abstract

Comment is made on the proposal by the Chemical Industry Advisory Board of the American Standards Association to substitute D-319 and D-319-L analyses of austenitic chromium-nickel-molybdenum stainless steel for Types 316 and 316-L stainless steel under certain conditions. NACE Technical Unit Committee T-5A found it could support the substitution of D-319 for 316 where deemed necessary, but wished at the same time to caution potential users against any blanket revision of their specifications. It was felt by T-5A that an adequate technical appraisal of the corrosion problem involved should be made before insisting upon the replacement of commercial 316 or 316-L. 6.25

Introduction

TECHNICAL Unit Committee T-5A has a special interest in the use of the D-319 and D-319-L analyses of austenitic chromium-nickel-molybdenum stainless steel. These materials have been proposed by the Chemical Industry Advisory Board of the American Standards Association as a substitute for Type 316 and 316-L stainless steel where superior corrosion resistance is required but the additional expense of Type 317 is not warranted. They carry ASME Code approval and the tentative recognition of the AISI and ASTM.

The development of the D-319 analysis is of interest in that it provides an average composition which embraces under one grade many of the special compositional limits demanded by chemical manufacturers for specific applications.

Molybdenum-bearing stainless steels, nominally 316 or 316-L, but also meeting the stricter limits of the D-319 or D-319-L analyses, have given highly satisfactory service in chemical plants for more than two decades. It can be stated without reservation that the proposed analyses can successfully substitute for 316 and 316-L in the vast majority of applications. Their equality with 316 and 316-L on a performance basis is a matter of record.

On the other hand, the special compositional requirements for 316 steels, from which the D-319 material arose, have been applied only to special cases. Chemical plants have bought conventional ASTM 316 for the majority of their applications, reserving their restricted proprietary specifications for these special problems.

So far as Committee T-5A is aware, no technical data have been adduced to indicate that the D-319 is inherently superior, always superior, or even superior in a significant number of cases, to commercial 316.

Therefore, while the committee can support the substitution of D-319 for 316 where deemed necessary, it wishes to caution potential users against any blanket revision of their specifications. An adequate technical appraisal of the corrosion problem should be made before insisting upon the replacement of commercial 316 or 316-L.

The committee wishes further to encourage a realistic appraisal of the alleged superiority of the D-319 analysis, with particular attention to the volume requirements as compared to applications where commercial 316 is entirely satisfactory. Technical information relative to these points is specifically solicited from the interested parties.

★W. H. Burton, General Chemical Division of Allied Chemical Corp., Camden, New Jersey, Chairman.

NACE Guide for Preparation of Articles for Publication

Persons interested in submitting articles on corrosion for publication in CORROSION can obtain upon request a copy of the "NACE Guide for Preparation of Papers." Write to CORROSION, National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas.

Stress Corrosion Screening Tests of Materials For Steam Generator Tubing in Nuclear Power Plants*

By D. E. WHITE and E. G. JOHNSON

Abstract

Nuclear power plant steam generator tubing materials were tested for their susceptibility to chloride stress corrosion cracking. Stressed U-bend specimens were exposed for 24 hours in a tilting autoclave to both the liquid and vapor phases of a high pH synthetic boiler water solution containing oxygen, phosphate, and 500 ppm of chloride ion. The results indicate that AISI Type 347 stainless steel, the control material, and Carpenter 7Mo are about equally susceptible to stress corrosion cracking in this test environment. Carpenter 20Cb and Type 304 having low carbon and nitrogen content displayed improved resistance. Inconel, Monel, nickel, and titanium displayed complete resistance. Ferritic steels were crack resistant but they did suffer pitting attack. 3.5.8

Introduction

AUSTENITIC STAINLESS steels have been used for some time as the basic material of construction for the primary system of pressurized water power reactor plants. The choice of this type of steel was based on corrosion resistance to the primary fluid, fabricability, and nuclear activation properties of the corrosion product. It has proven to be a wise choice, as demonstrated by the very successful operation of several plants of the pressurized water type. Since austenitic stainless steels have been shown to be sensitive to chloride stress corrosion cracking,[1,2] however, the steam generator represents a potential problem area because the secondary system of a nuclear reactor power plant is subject to the same impurities, contaminants, and inleakage as any normal boiler feedwater system.

It is virtually impossible to prevent at least some contamination by chlorides in the feed or make-up system of a plant using sea water coolant. It is also impossible to avoid the presence of rather high operational and residual stresses in a unit as structurally complex as a large pressurized heat exchanger. Thus, the necessary conditions are present to produce chloride stress-corrosion cracking in a material such as austenitic stainless steel.

In anticipation of the problems that could arise from stress corrosion cracking on the secondary side of the steam generator tubing, the following two operations have been carried out:

(1) Evaluation of chemical inhibitors for addition to the secondary side (boiler) water.[3]

(2) Evaluation of alternate materials not subject to chloride stress corrosion cracking for steam generator tubing.

It is the second approach with which this paper is concerned. This work was done to screen materials to determine their resistance to chloride stress corrosion cracking. With this purpose in mind, the test was designed to be severe. It was essential for effective control purposes that a high percentage of the austenitic stainless steel control specimens could be made to fail. All other materials could then be compared to the stainless steel to see if they displayed increased resistance to chloride stress corrosion cracking.

Experimental Procedure

All tests in this program were run in an autoclave, schematically shown in Figure 1. This vessel was fabricated from Monel according to ASME Code requirements for operation at 900 psi. The autoclave was equipped with a sample line and cooling coil connected into the bottom for obtaining water samples. A pressure gauge and a pressure safety disc were present in the removable head with suitable high pressure valves.

The autoclave was also provided with auxiliary equipment so that it could be tilted through 180 degrees at accurately timed intervals. In this test program, the autoclave remained in a vertical position with removable head upward until operating temperature was attained, at which time the tilt cycles began. The autoclave was then tilted 180 degrees requiring 30 seconds for actual tilting. It was held in this inverted position for 4½ minutes when it was again tilted back to its original position in the required 30 seconds, and then held for 4½ minutes. This comprised one tilt cycle of ten minutes. The autoclave subsequently continued to operate in this fashion throughout the 24-hour test period during which time 144 complete tilt cycles were accomplished.

The specimens employed in this project were of the U-bend type as described below. They were supported in a fixed position within the autoclave by means of a Type 304 stainless steel specimen support rack which prevented contact of specimens with each other as well as with any part of the autoclave. Each specimen positioned on the rack was numbered for identification of location.

White Johnson

D. E. WHITE is a materials application engineer at Westinghouse's Bettis Atomic Power Laboratory. He has a BS from the U. S. Merchant Marine Academy and a BS in metallurgical engineering from Case Institute of Technology.

EDMUND G. JOHNSON has been with Nalco Chemical Co., Chicago, Illinois, since 1937 and now serves as Chief Metallurgist. His principal field of work has been the diagnosis of all types of metal failures, especially those related to boilers and auxiliary equipment, as well as stress corrosion work with both mild and stainless steels. He has a PhD in physical chemistry from Brown University.

The desired temperature in the autoclave was maintained by means of strip heaters arranged radially around the autoclave. The control thermocouple was located between two heaters in the autoclave jacket and connected with a 0-1100 degree F temperature controller which maintained the desired autoclave temperature.

The temperature of the test solution inside the autoclave was determined by a second thermocouple, extending 15 inches through the bottom of the autoclave and running one-half inch from the inside wall. This thermocouple was connected to a 0-1000 F temperature recorder with a strip chart which provided a permanent temperature record.

The test evaluation equipment included a 5X magnifying glass for general screening. In addition, the latest type stereoscopic microscope was used for very careful examination of specimens. This instrument was capable of magnifications up to 80X. Complete equipment was also available for fluorescent penetrant inspection.

The operational procedure was the same for all tests in this program and is described in the following paragraphs.

All solutions used in this test program were made from high purity water. The chemical content of each test solution was as follows:

Phosphate, added as disodium phosphate, 250-350 ppm as PO_4. Chloride, added as diluted synthetic sea water, 500-550 ppm as Cl. pH adjusted with sodium hydroxide to 10.6-11.2. Oxygen at time of charging autoclave, 7-9 ppm (air saturation at room temperature).

All chemicals added were of reagent grade or the highest available purity. Stock solutions of disodium phosphate, synthetic sea water, and sodium hydroxide were prepared in advance for use in making up each test solution. The synthetic sea water was prepared according to ASTM-D-1141 specification. Samples of the test solution were taken for analysis of the initial solution at time operating

★Submitted for publication December 30, 1958. A paper presented at a meeting of the Western Region, National Association of Corrosion Engineers, Los Angeles, California, Nov. 17-20, 1958.

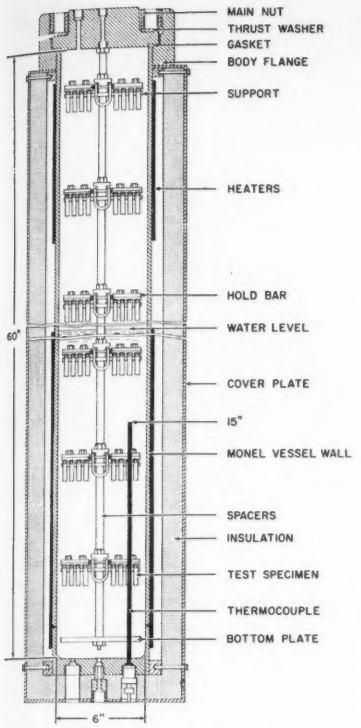


Figure 1—Autoclave assembly for chloride stress corrosion tests.

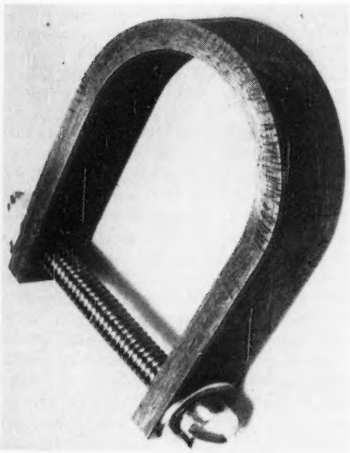


Figure 2—Deflected Type 347 stainless steel specimen after cracking test. Specimen is shown at approximately full size.

temperature of autoclave was reached, after 12 hours operation, and at the end of 24 hours operation.

The U-bend specimens used were fabricated from bars made from annealed sheet rock reduced to ⅜ in. x ⅛ in. x 3¾ in. These specimens had a 3/16 in. hole drilled in either end and were formed into a U-bend with the legs being nearly parallel. The specimens were quite uniform in all respects as it is possible to bend specimens to very close tolerances by employing fixtures and careful bending procedures. The desired stress level was obtained by fastening the legs together with a stainless steel bolt and tightening the nut so that the two ends were drawn together to a predetermined micrometer measurement. This distance was always sufficient to insure that all specimens would be stressed to the yield point. This is very important inasmuch as plastic deformation appears to be a necessary condition for establishing crack sensitivity. The high incidence of cracking obtained with the Type 347 stainless steel (the control material), indicates proper stressing for adequate crack development.

After stressing, the specimens were critically examined with a stereoscopic microscope at 30 or more diameters. They were also examined by the fluorescent penetrant method. No cracks were found on any of the specimens prior to testing. However, many specimens were discarded because nicks, gauges, or surface flaws rendered them unsuitable. Before attachment to the support rack, the specimens were degreased with acetone and subsequently all specimens were handled with clean lint-free gloves. Test specimens were arranged on the rack in such a manner that one half of the specimens were immersed in the liquid in the bottom half of the autoclaves at the start of the test while the remainder were located in the top half and above the liquid level. Specimens in these locations will be referred to throughout this report as "Liquid Phase" and "Vapor Phase" specimens respectively.

During the three hours required to reach the operating temperature of 500 F, the autoclave remained in its original upright position. During this time, the specimens that had been loaded into the bottom half of the autoclave or liquid phase remained submerged while those in the top half or vapor phase were in the space above the test solution. The attainment of operating temperatures signaled the actual start of the test and the accompanying starting of the tilt cycles. The time of cycles was carefully maintained at exactly 10 minutes. The autoclave then operated for 24 hours or 144 continuous tilt cycles at the 500 F operating temperature. This constituted the actual test period. The final tilt put the autoclave in a vertical position with the removable head at the top. At this time, the tilting mechanism and heaters were turned off. To accelerate cooling, a blower was attached to the bottom of the autoclave and air was forced between the autoclave jacket and the insulating shell. When the temperature of the water reached 185 F, the blower was shut off and the autoclave head removed. The specimen support rack was taken out, the specimens detached and put in a desiccator. The volume of the remaining test solution was recorded and a portion set aside for possible future analysis.

At the conclusion of each test, the specimens were examined for cracks while still in a stressed condition at magnifications up to 80X. Sometimes, cracks were found only at the higher magnifications. A build-up of oxide corrosion products usually covered the mouth of the crack and greatly aided in their detection. Specimens in which no cracks had been found were examined again by the fluorescent penetrant method. If no cracks had been found by any of the above methods, the specimens were considered to be uncracked.

At least four specimens were taken for metallographic examination from each test. Whenever possible, this included one cracked and one uncracked specimen from each phase. In addition, the few specimens which were listed as doubtful were examined metallographically.

TABLE 1—Summary of Test Results

Test No.	Material	LIQUID PHASE		VAPOR PHASE	
		Cracked	Not Cracked	Cracked	Not Cracked
1	Type 347 Stainless Steel	36	0	36	0
2	Inconel	0	36	0	36
3	304 Elcn (Vacuum Melted)	2	20	0	22
	Type 347	14	0	14	0
4	Croloy 16-1	0	36	0	36
5	Nickel (Commercially Pure)	0	36	0	36
6	Monel	0	36	0	36
7	Titanium (Commercially Pure)	0	36	0	36
8	Carpenter 7 Mo	18	0	18	0
	Carpenter 20 CB	0	18	18	0
9	Nickel Plated Type 347	18	0	18	0
	Type 347 (Passivated with Dilute HNO_3)	18	0	18	0
10	SA 210 (Carbon Steel)	0	18	0	18
	Croloy 2¼	0	18	0	18

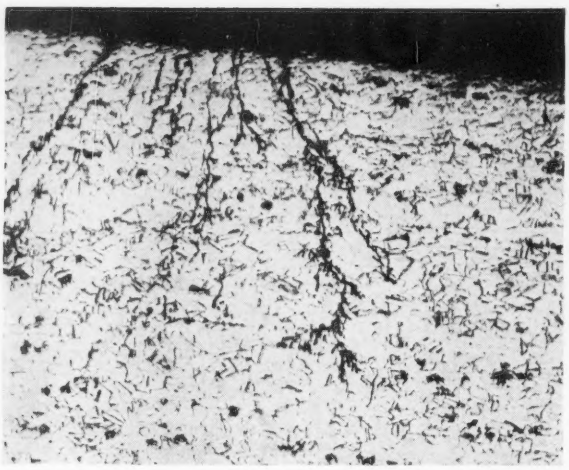


Figure 3—Autoclave Test No. 1 showing Type 347 stainless steel austenitic structure and typical stress corrosion cracks. Approximately 160X, modified acid ferric chloride etch.

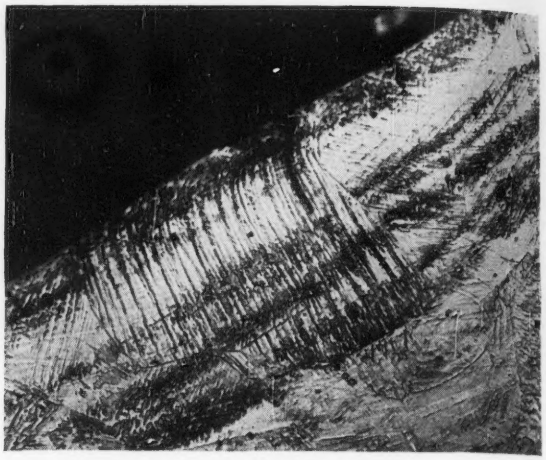


Figure 4—Type 304 ELCN stainless steel showing metal structure of austenite with some ferrite and martensite. Note small cracks at surface. Approximately 400X, modified acid ferric chloride etch.

The metallographic examination accomplished the following objectives:

1. It determined the structure of the metal
2. It provided evidence that the cracks found on stereoscopic microscope examination were true stress corrosion cracks
3. It indicated that no cracked specimens were being overlooked by the other methods of specimen evaluation.

Results

The results of this series of tests are given in Table 1, which shows the number of specimens cracked for each material in each test. In addition, an attempt was made to estimate the relative incidence of cracking of the various materials. Ten specimens were selected at random for each test, five from each phase. The number of cracks on each specimen was determined by actual count after examining all available surfaces. The relative size of the cracks was also noted. A typical cracked specimen is shown in Figure 2.

The results of the metallographic examination of each material were as follows:

Type 347 Stainless Steel

Figure 3 shows a stress corrosion crack in the Type 347 stainless steel used as a control material. The metal structure is austenite with some ferrite. The cracking is transgranular and typical of a stress corrosion crack found in austenitic stainless steels.

All of the Type 347 specimens used in the program, in both liquid and vapor phases, developed stress corrosion cracks.

Inconel

Metallographic examination of the Inconel revealed a single phase structure of varying grain size. This alloy has the approximate composition of 75 Ni, 15 Cr, and 7 Fe. There is some evidence that carbides may also be present.

None of the 72 Inconel specimens developed cracks under the conditions of test exposure.

Type 304 ELCN Stainless Steel

Figure 4 is a photomicrograph of the Type 304 ELCN stainless steel used in Test 3. As indicated by the letter designations, the carbon and nitrogen content of the metal have been kept very low by a vacuum melting technique. The structure shown is austenitic, but both martensite and ferrite are present which render the metal slightly magnetic. Apparent cracking occurred in only 2 out of 22 specimens in the liquid phase and in none of the 22 specimens in the vapor phase. The apparent cracks found under the stereoscopic microscope were very tiny and only a very few cracks were located on subsequent metallographic examination. These cracks were too small to be diagnosed as true stress corrosion cracks although the conditions of testing should favor such cracking.

The retention of such tiny cracks for metallographic study presents some problems. Ordinary cutting and grinding operations are too crude to preserve the crack by one metallographic series of cutting, grinding and polishing. The method employed was to make specimen cuts far enough from the crack so that one cycle of grinding and polishing would not remove enough metal to reach the crack. The crack is then slowly approached by repeatedly removing small amounts of metal by alternate fine grinding and polishing.

Fourteen Type 347 stainless steel specimens were included in the top half of the autoclave and fourteen in the bottom half. All cracked in this test.

Croloy 16-1

Croloy 16-1 contains approximately 16 percent chromium and 1 percent nickel and has a structure of martensite and ferrite. The alloy was subjected to heavy oxidation or scaling during the test. Localized corrosive attack was found under the heavy iron oxide layer at the convex side of the U-bends. This attack seemed to be favored by the martensite, but resisted by the ferrite. These pit-like areas were thick and blunt, so that they most closely resembled low frequency corrosion fatigue cracks, although some might consider them to be merely extended corrosion pits. These microscopic features are shown in Figure 5. In order to examine these specimens thoroughly, it was necessary to first remove the scale by electrolytic descaling.

Nickel

The nickel metal employed in the test, showed good structure although there was a considerable variation in grain size. A cyanide persulfate etch was required in order to preserve finely dispersed inclusions such as graphite or nickel sulfide which were removed by other etchants. No cracks were found on any of the nickel U-bend specimens.

Monel

The Monel metal used in fabricating these U-bends was a single phase alloy of rather uniform grain size. There was some rippling of the metal surface on etching. This is probably due to prior straining of the metal during the formation of the U-bends. No cracks were found in any of the specimens used in this test. In order to provide a check on the autoclave material, two Monel specimens were inserted in each test for control purposes. The same two specimens were used throughout the entire test series with no cracking.

Titanium

The titanium metal in Test No. 8 displayed a structure of alpha plus beta titanium with a basket-weave structure in some areas. None of the 72 specimens used developed cracks. No pitting was noted.

Carpenter 7 Mo

Metallographic examination of Carpenter 7 Mo revealed a structure which most closely resembles a ferritic stainless steel with carbides present as spheroids which were oriented in bands. The alloy was strongly magnetic.

In Test No. 8 all 36 of the Carpenter 7 Mo specimens developed transgranular stress corrosion cracks.

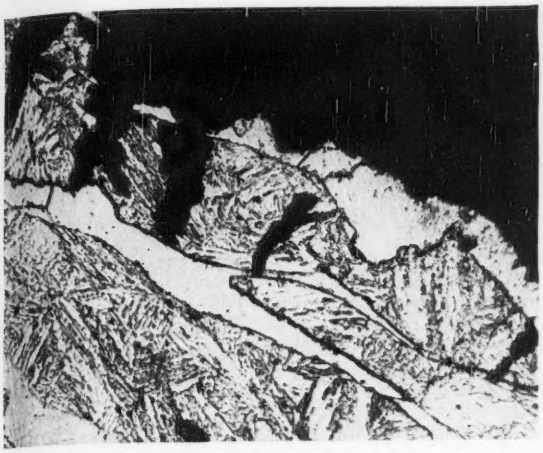


Figure 5—Croloy 16-1 stainless steel showing martensite and ferrite structure. Ruptures occurred under oxide layer and are limited to the martensite. Approximately 400X, Vilella's etch.

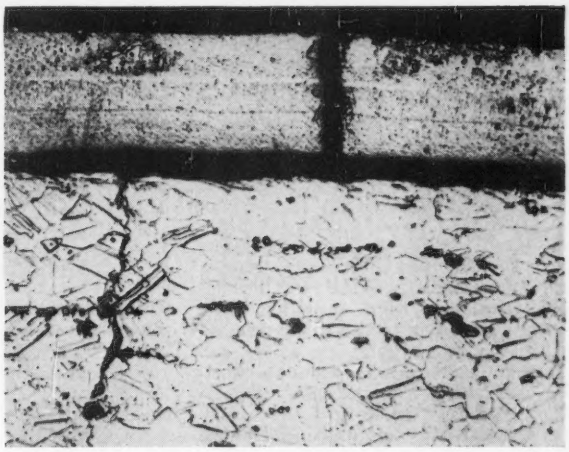


Figure 6—Nickel plated Type 347 stainless steel showing rupture of plating and crack in underlying stainless steel. Approximately 400X, modified acid ferric chloride etch.

Carpenter 20 Cb

Carpenter 20 Cb stainless steel etched with much more difficulty than did the Type 347 and Type 304 stainless grades. The structure was austenitic and while most grains were quite small, a few were very large by comparison. All of the 18 specimens in the vapor phase developed cracks of the typical, transgranular, stress corrosion type. None of the 18 specimens in the liquid phase were cracked.

Nickel-plated Type 347 Stainless Steel

Test No. 11 employed 36 Type 347 stainless steel U-bends which had been nickel-plated. Each specimen had been abraded at two points on the convex side of the bend thus exposing the underlying Type 347 alloy. All specimens developed stress corroson cracks both in the abraded areas and at other points where failure of the nickel plating had occurred. Figure 6 shows a photomicrograph of a failed region. The nickel plating is present in layers and is not bonded to the underlying stainless steel.

The 347 stainless steel shows its usual austenitic structure and the cracking is of the stress corrosion type. The crack is some distance away from the opening in the nickel plate instead of being directly below it. This would signify that this is a true crack and not a mere extension of the rupture in the nickel plate. Furthermore, the position of the crack may be an indication that concentration of boiler water solids may have occurred in the crevice between nickel plate and underlying metal. It is also clear that the nickel plating did not give anodic protection to the Type 347 stainless steel.

Thirty-six specimens of a selected heat of Type 347 stainless steel were also included in Test No. 11—eighteen specimens in each phase. These specimens had been passivated in the stressed condition in 20 percent nitric acid for 30 minutes at 145 F. All specimens developed stress corrosion cracks.

Croloy 2¼

Croloy 2¼ is an alloy which contains 2¼ percent chromium and 1 percent molybdenum and has much better high temperature properties than does carbon steel. All 36 Croloy 2¼ specimens in Test No. 10 were uncracked, but rather heavy oxidation or scaling occurred.

Carbon Steel

In Test No. 10, 36 carbon steel U-bends were employed. The metal possessed a spheroidized carbide structure rather than the pearlitic structure normally present. In most applications, it has been found that the spheroidized structure will render the steel less corrosion resistant. None of the 36 specimens cracked, but as expected, the carbon steel was severely scaled due to the oxidizing conditions of the test.

Discussion

The alloys tested in this program were selected first for their expected resistance to chloride stress corrosion cracking, and secondly, for their fabricability, cost, and nuclear activation properties. It is not surprising then, that a high proportion of the alloys did finish the test crack-free. It was somewhat striking, however, that for the most part, each alloy displayed either a 100 percent cracking rate or zero percent.

At the time that the statistical design of this test series was prepared, it was anticipated that the alloys to be tested would present a wide range of susceptibility to chloride stress corrosion cracking; that is, it was expected that the cracking rates from alloy to alloy would vary more or less continuously from zero to 100 percent. Accordingly, the statistical design was prepared to demonstrate a 20 percent minimum failure rate for the Type 347 control material at a confidence level of 95 percent and a maximum failure rate of 10 percent for those materials to be considered for further study. In order to do this, it was calculated that at least 36 specimens would be required in each phase of each test. It was expected that any alloy displaying a failure rate of more than 10 percent would not be a significant improvement over stainless steel. As can be seen, this analysis turned out to be inapplicable to this program since the cracking incidence was such that the specimens cracked profusely or not at all. The vacuum melted 304, designated ELCN for its low carbon and nitrogen content, was the only alloy that displayed a very low cracking rate. Carpenter 20 Cb cracked 100 percent in the vapor phase and not at all in the liquid phase. All the other materials either cracked 100 percent or not at all in both phases. These data substantiate the usefulness of this test for screening materials. The test demonstrated high selectivity for chloride stress corrosion cracking, and the data were subsequently supported by model boiler evaluation.

In further reference to the performance of the Carpenter 20 Cb alloy, it should be pointed out that other tests in tilting autoclaves have demonstrated that the vapor phase, as defined in this program, is more aggressive. Higher cracking rates in the specimens initially and finally exposed in the vapor phase are not unusual. The data for Carpenter 20 Cb may be interpreted as an indication that this alloy has increased resistance to chloride stress corrosion cracking in this test environment compared to Type 347, but that this increase in resistance is not enough to result in complete specimen integrity.

The chemistry of the water solution was established within the specified limits at the beginning of each test and monitored throughout the test period. Some variations occurred during the test by virtue of the fact that a static autoclave was used without provision for chemical replenishment. For instance, the phosphate concentrations diminished during each test due to reaction with the calcium and magnesium of the synthetic sea water. In several cases, the pH dropped slightly below the specified minimum of 10.6. But in no cases were any of these variations considered to have been severe enough to have compromised the validity of the tests.

The test reproducibility was amply demonstrated in a parallel program test-

ing chemical inhibitors for stress corrosion cracking. Several control runs were made using the same apparatus, procedure, and water chemistry as listed above. All of the Type 347 specimens were cracked in each of these tests.

Some features of this test are rather specialized in nature, and arose from the basic purposes for which the test was designed (that is, the screening of potential steam generator tubing.) For example, the chloride level of 500 ppm was selected because it represents the current maximum specified level for nonnuclear naval boiler operation. The oxygen saturation condition was selected to make the test relatively severe and simulate ineffective deaeration or "start-up" conditions. The phosphate level was chosen to correspond to normal Navy boiler water treatment practice. The test duration of 24 hours was selected only because it was known that the control material could be cracked in this length of time in this very aggressive environment. The tilting was introduced to simulate the alternate wetting and drying action that takes place in those portions of the boiler where steam blanketing can occur. It also provided a solids concentration mechanism on the specimen surface as would take place in the tube sheet crevices.

Summary

In this investigation, Inconel, Monel, nickel, and titanium were completely free of cracking or pitting. Their surfaces were covered with a light oxide tarnish film in each case. These alloys were recommended for further study in model boiler tests.

Croloy 16-1 was free of stress corrosion cracking, but it did display considerable pitting. It should be emphasized that the attack on the Croloy 16-1 was not as severe as that observed on either the SA-210 (carbon steel) or the Croloy 2¼. Furthermore, it is reasonable to expect that Croloy 16-1 would perform satisfactiorily where the oxygen was held to those lower levels found in normal boiler operation. This alloy was also recommended for further study in model boilers.

A very interesting characteristic of the attack that took place in the Croloy 16-1 is that it seemed to be preferential to the martensitic grains of this two-phase alloy. Photomicrographs reveal that these pits stopped at the ferrite interfaces, and in some cases, completely encircled a ferrite grain. This would suggest that an all ferritic chromium stainless steel may be more suitable for steam generator tubing, at least from a pitting standpoint.

The vacuum melted Type 304 designated ELCN for its extra low carbon and nitrogen contents was prepared as a special heat by vacuum melting. This alloy contained from 10 to 15 percent ferrite as a result of having these two very strong austenizers removed. It displayed only two very small cracks in 44 specimens. Whether the presence of 10 to 15 percent ferrite in the structure or simply the "cleanliness" of the alloy from vacuum melting could account for the superior resistance of this alloy to chloride stress corrosion is not known.

A test of nickel plated Type 347 was included in this test series because there was reason to believe that nickel plate would protect austenitic stainless steel from stress corrosion cracking. It was clear that a defect-free plate could never be attained throughout a full size steam generator; therefore, the only chance for any plating to be completely effective would be if it were anodic to the substrate. To examine this feature of nickel plating, defects in the form of ground spots and bend fissures were purposely introduced in the stressed portion of these specimens. Since cracking occurred on all of the specimens under the plating near the fissures, it was assumed that the nickel plating did not provide anodic protection.

References

1. W. F. Williams and J. F. Eckel. Stress Corrosion of Austenitic Stainless Steels in High Temperature Water. *J. Am. Soc.*, 68, 93-103 (1956).
2. C. Edeleanu and P. P. Snowden. Stress Corrosion of Austenitic Stainless Steel in Steam and Hot Water Systems. *J. Iron and Steel Inst.*, 406-422 (1957) Aug.
3. J. H. Phillips and W. J. Singley. Screening Tests of Inhibitors to Prevent Chloride Stress Corrosion. *Corrosion*, 15, 450t (1959) Sept.

Acknowledgment

The work on which this paper was based was performed by the National Aluminate Corp. under a subcontract with the Bettis Atomic Power Laboratory. The Bettis Laboratory is operated by the Westinghouse Electric Corporation for the Atomic Energy Commission.

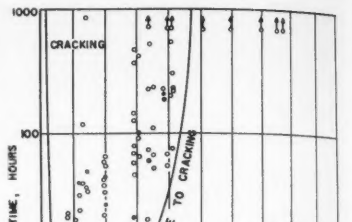


Figure 7—Stress corrosion cracking of iron-chromium-nickel wires in boiling 42 percent magnesium chloride.

DISCUSSION

Comments by C. M. Schillmoller, The International Nickel Co., Inc., Los Angeles, California:

I would like to compliment Mr. White on his interesting discussion of the stress corrosion screening tests. Research studies by The International Nickel Company carried out at the Bayonne Laboratories essentially confirm your findings. We found that the susceptibility of the steels to chloride stress cracking tied in closely with the percent nickel content in the steel, the 18-8 Cr-Ni alloys being most susceptible while the resistance increased by addition of nickel. Alloys without nickel or with 42 percent nickel and over, showed freedom to stress corrosion cracking in a chloride containing environment. This includes alloys such as Ni-o-nel (42 percent Ni), Monel (70 percent Ni) and Inconel (78 percent Ni). The data shown in Figure 7 on stress cracking of stainless steel wires in boiling magnesium chlorides may be of interest.

You are probably aware of the evaluation tests by Battelle and others on acceptance of Inconel for steam generator tubing in pressurized water nuclear power plants. Also, at Idaho Falls an Inconel bundle is being installed in a test reactor installation.

Any discussion of this article not published above will appear in December, 1960 issue.

Stress Corrosion of Steels For Aircraft and Missiles*

By E. H. PHELPS and A. W. LOGINOW

Abstract

Atmospheric stress corrosion tests have been conducted on alloy and stainless steels intended for use in high-speed aircraft and missiles. The results of these tests showed that very high strength alloys hardened by heat-treatment, like many nonferrous alloys used in conventional aircraft, are under certain conditions susceptible to atmospheric stress corrosion cracking. Tempering at temperatures of 1100 F and above confers resistance to stress corrosion. Also, the test results indicated that austenitic stainless steels hardened to very high strength levels by cold working are not susceptible. Protective coatings that are anodic to steel appear to be very effective in preventing stress corrosion. A correlation between the specimen tests presented in this paper and service performance has not been established. The test results should be regarded as a guide to effective utilization of steels in aircraft and missile applications, but they should not be regarded as a direct indication of expected service performance.

The microstructural characteristics of stress corrosion cracks in aircraft and missile steels are discussed. Experiments on the mechanism of cracking indicate that stress corrosion in a 12 percent chromium martensitic stainless steel heat-treated to a very high strength is the result of corrosion along an active path in the metal and is not the result of hydrogen induced in the metal by corrosion. 3.5.8

Introduction

THE HIGH speed of aircraft and missiles has necessitated the use of materials with high strength at ambient and elevated temperatures. Steel meets these requirements and is being used more extensively now than ever before in aircraft and missiles. This increased usage has led to an extensive amount of research by steel producers to assist aircraft and missile manufacturers in their efforts to utilize the excellent properties of steels in aircraft and missile design.

In the development of steels for these applications, it is first necessary to establish that the mechanical properties at ambient and elevated temperatures are sufficient to meet the stringent requirements posed by aircraft and missile manufacturers. However, the evaluation of corrosion and stress-corrosion properties is also necessary to insure proper utilization. The excellent general corrosion resistance of the stainless steels is well known, as are methods for preventing general corrosion of steels other than stainless steels. The stress corrosion properties of aircraft and missile steels, however, are not as well known.

The purpose of this paper is to present the results of atmospheric and laboratory stress corrosion tests that have been conducted on very high strength steels intended for aircraft and missile applications. The types of steels being considered for these applications are (1) alloy steels, (2) 5 percent chromium hot-work die steels, (3) 12 percent chromium martensitic stainless steels, (4) semiaustenitic precipitation-hardenable stainless steels, and (5) cold-worked austenitic stainless steels. Most of the previous work on stress corrosion of very high strength steels described in the literature has been limited to the 12 percent chromium martensitic stainless steels[1, 2, 3] and the semiaustenitic precipitation-hardenable stainless steels.[4, 5] Recently, failures of hot-work die-steel solid-fuel rocket chambers during hydrostatic testing have been attributed to hydrogen introduced into the metal by localized corrosion.[6] Conditions under which cracks can be initiated by stress corrosion and propagated by brittle fracture have been described.[7]

Experimental

The atmospheric tests reported in this paper were made with bent-beam specimens of the type shown in Figure 1. The holder used was made of AISI Type 302 stainless steel. The thickness of the specimens ranged from approximately 0.050 inch to 0.020 inch. The specimen widths were 1 inch for the thicker specimens and 0.57 inch for the thinner specimens. The holder span used was 7 inches for the thicker specimens and 4 inches for the thinner specimens. The use of bent-beam specimens for atmospheric stress corrosion tests has been described previously.[8]

The specimens were sheared from sheet stock to the proper width, but to a length longer than was to be used in the tests. All specimens were sheared longitudinal (parallel) to the rolling direction except where noted. The specimens were then heat-treated to the desired properties. After heat-treatment, the specimen surfaces were ground on an 80-grit dry emery belt to remove heat-treating scale and any visible surface defects. This treatment was followed by grinding on a 120-grit emery belt. The specimens were then cut to the appropriate lengths to produce the desired stress after bending, degreased in trichloroethylene vapor, washed in distilled water, and rinsed in acetone. The specimens were then stored in a desiccator until the tests were to be initiated.

The appropriate length of the specimens was determined by a relationship, shown graphically in Figure 2, between the strain in the outer fibers at the middle of the specimen, the specimen length, the specimen thickness, and the holder span. This relationship is based on the exact solution for an elastic beam and does not involve the approximations included in the equation presented in reference 8. The derivation of the relationship will be presented in a separate paper now being prepared.

The stressed specimens were mounted on atmospheric-corrosion-test racks as shown in Figure 3. The specimens were stressed by bending them and placing them in the holder after the holder had been fastened to the test rack. Inspection of the exposed specimens was performed daily for the first two weeks, every two days for the following two weeks, and twice a week thereafter. A specimen was considered to have failed if it fractured or if it contained a crack that was visible with the unaided eye.

Atmospheric stress corrosion tests were conducted at the 80-foot lot at Kure Beach, North Carolina, and at Monroeville, Pennsylvania. The atmosphere at the 80-foot lot contains sea-water spray and therefore is a very severe corrosive environment. The atmosphere at Monroeville is a moderately corrosive semi-industrial environment.

Materials

Typical chemical compositions for the steels used in this work are shown in Table 1. Where more than one heat of steel was tested, the analysis shown represents an average analysis. The composition of the individual heats is not included because appreciable differences in the stress corrosion behavior of different heats of the same steel were not observed. Also, where comparisons could be made, commercial heats of a steel showed about the same stress corrosion behavior as laboratory induction heats.

Phelps Loginow

E. H. PHELPS is assistant division chief in the Chemical-Metallurgy Division, Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa. A member of NACE and the Electrochemical Society, he has a BS from Clarkson College of Technology and an MS and PhD from Case Institute of Technology.

ALEXEI W. LOGINOW is associated with the Applied Research Laboratory, U. S. Steel Corp., Monroeville, Pa. A member of NACE and ASM, he has a BS in metallurgical engineering from Carnegie Institute of Technology. His work is in stress corrosion research on stainless, alloy and carbon steels.

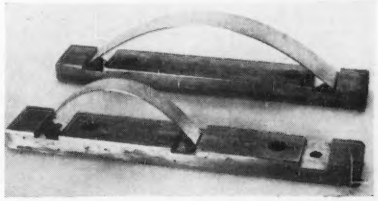


Figure 1—Bent-beam specimens used in atmospheric stress corrosion tests.

* Submitted for publication February 3, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

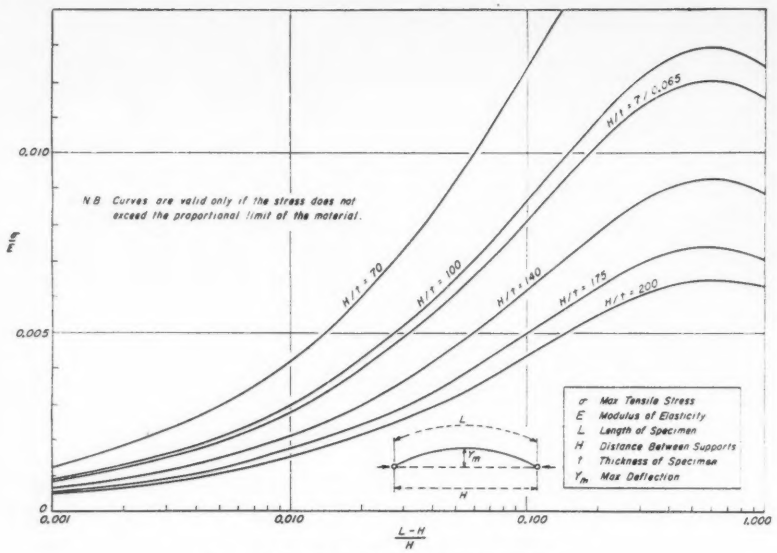


Figure 2—Tensile stress in strip corrosion specimen.

Figure 3—Test rack with bent-beam stress corrosion specimens and tensile specimens.

The heat-treatment and mechanical properties of the various steels are shown in Table 2. With a few exceptions, the yield and tensile strengths of the steels are above 200,000 psi.

Stress Corrosion Behavior of Steels

The results of atmospheric stress corrosion tests conducted at Kure Beach are summarized in Table 3. Included in this table are test results on alloy steels, hot-work die steels, 12 percent chromium martensitic stainless steel, semiaustenitic precipitation-hardenable stainless steels, and cold-rolled and stress-relieved austenitic stainless steels. The data shown were obtained at a stress level of 75 percent of the yield strength.

The alloy steels, USS Airsteel X200, USS Strux, MBMC No. 1, and AISI 4340, with yield strengths ranging from 218,000 psi to 254,000 psi, were subject to failure in times ranging from 6 to 11 days. AISI 4130, with a yield strength of 157,000 psi, was not subject to failure in 175 days of test. Although the available data do not permit a general statement, the excellent stress corrosion resistance of AISI 4130 is considered to be an indication that other alloy steels heat-treated to a yield strength of about 150,000 psi would have equally good stress corrosion resistance.

The hot-work die steels tempered at 1000 F to produce a yield strength of 229,000 to 237,000 psi failed in an average time of 4 days. The behavior of the hot-work die steels, Types A, B, and C, was approximately the same. The resistance of these alloys was substantially improved when they were tempered at 1100 F, although as expected their yield strengths were reduced by this treatment. Failures have not occurred after 750 days of test with 15 specimens, and the 3 specimens that failed exhibited a very long failure time of 250 days. The large difference in performance between the specimens that did not fail and those that did fail cannot be explained and appears to be a probability effect. A relatively short time to failure was observed for 12 MoV stainless steel tempered at 900 F. It will be shown later that this steel is resistant when tempered at 1100 F and above.

The semiaustenitic precipitation-hardenable stainless steels showed average failure times ranging from 1 day to 47 days. However, a number of the specimens tested have not shown failure in times ranging from 240 to 380 days. Here again, the difference in performance between the specimens that did not fail and those that did fail is believed to be a probability effect. This effect was observed in several different exposures made at different seasons and therefore is not attributed to a seasonal variation in the environmental conditions at the Kure Beach test lot.

TABLE 1—Composition of Alloys

Steel	ANALYSIS, PERCENT													
	C	Mn	P	S	Si	Ni	Cr	Mo	V	Ti	N	Al	W	B
USS Airsteel X200*	0.39	0.93	0.009	0.014	1.51	....	2.00	0.48	0.07	....	....	0.04	....	....
USS Strux	0.38	0.87	0.010	0.008	1.45	0.60	0.82	0.52	0.05	0.03	....	....	....	0.001
MBMC No. 1	0.43	0.92	0.011	0.015	1.35	....	0.69	0.03	0.07	....	....	....	....	....
AISI 4340	0.39	0.79	0.014	0.019	0.25	1.78	0.79	0.25	0.005	<0.005	0.010	0.06	....	....
AISI 4130	0.25	0.50	0.006	0.011	0.22	0.01	0.95	0.19	<0.005	<0.005	....	0.033	....	....
AISI 4335+V	0.35	0.75	0.005	0.012	0.23	1.42	0.68	0.32	0.20	....	....	....	....	....
Hot-Work Die Steel, Type A*	0.45	0.60	0.011	0.017	0.68	0.34	5.09	1.17	0.52	....	....	....	....	....
Hot-Work Die Steel, Type B	0.47	0.59	0.003	0.016	0.72	0.42	5.30	1.73	0.26	....	....	....	0.99	....
Hot-Work Die Steel, Type C	0.53	0.50	0.002	0.017	1.08	1.50	5.33	1.80	0.96	....	....	....	....	....
USS 12 MoV Stainless Steel*	0.25	0.50	0.019	0.015	0.45	0.63	12.16	0.98	0.33	....	....	....	....	....
USS Stainless W*	0.081	0.73	0.015	0.013	0.78	6.66	16.72	0.21	....	0.90	0.034	0.24	....	....
Precipitation-Hardenable Stainless Steel, Type A*	0.076	0.65	....	0.009	0.36	7.17	16.89	....	....	0.077	....	1.22	....	....
Precipitation-Hardenable Stainless Steel, Type B	0.072	0.68	....	....	0.32	6.94	14.79	2.47	....	0.063	....	1.13	....	....
USS 17-5 MnV Stainless Steel	0.11	13.50	0.019	0.012	0.70	4.61	16.19	2.00	0.92	....	0.36	....	....	....
USS TENELON Stainless Steel	0.096	15.10	0.022	0.008	0.50	0.43	17.96	....	....	....	0.46	....	....	....
AISI Type 201 Stainless Steel	0.10	7.73	0.029	0.021	0.33	4.60	16.53	....	....	....	0.16	....	....	....
AISI Type 202 Stainless Steel	0.12	7.54	0.043	0.009	0.46	4.58	17.90	....	....	....	0.16	....	....	....
AISI Type 301 Stainless Steel	0.09	1.24	0.026	0.018	0.50	6.98	17.56	....	....	....	....	....	....	....

* More than one heat of steel tested.

Excellent resistance to atmospheric stress corrosion cracking was exhibited by the cold-worked and stress-relieved austenitic stainless steels. No failures have been observed on these steels in times ranging from 240 to 370 days. In addition to their excellent resistance to stress corrosion, these promising steels have very high yield and tensile strengths.

The results of tests conducted on the exposure racks at Monroeville, Pennsylvania, are shown in Table 4. The data shown indicate that the semi-industrial atmosphere in Monroeville can produce stress corrosion of certain high-strength aircraft alloys. The times to failure, however, were substantially longer than at Kure Beach, and no failures were observed on the semiaustenitic precipitation-hardenable steels in 520 days of test.

Effect of Stress Level

The results of experiments at Kure Beach to determine the effect of stress level on time to failure are shown in Table 5. Specimens were exposed at stress levels of 50, 75, and 90 percent of yield strength in these experiments. Generally, the time to failure increased as the stress level decreased. Airsteel X200 and the hot-work die steel, however, exhibited about the same time to failure at the three-stress levels. The results obtained on the semiaustenitic precipitation-hardenable stainless, Type A, hardened by refrigeration and aging at 950 F, indicate that a threshold stress level below which failure does not occur may exist for this alloy. It is not known whether a threshold stress exists for the other steels.

The effect of rolling direction was examined with two of the steels shown in Table 5. Specimens were cut longitudinal (parallel) to the rolling direction and transverse to the rolling direction. The results obtained with the alloy steel MBMC No. 1 were approximately the same for the longitudinal specimens as for the transverse specimens. Longitudinal specimens from AISI 4335 + V did not exhibit failure at any of the stress levels tested, whereas transverse specimens from this steel failed in 15 to 25 days at the two highest stress levels. A substantially higher yield strength in the transverse direction than in the longitudinal direction was also observed for this steel.

Effect of Corrosion on Mechanical Properties

Six stressed specimens at each stress level were exposed to obtain the data in Table 5. In addition, six unstressed tensile specimens and six specimens from which tensile specimens could be machined (tensile blanks) were also exposed in each series. After at least three of the stressed specimens had failed in each series, the remaining stressed specimens, three tensile specimens, and three tensile blanks were removed from the racks. Three tensile specimens and three tensile blanks were left on the racks for a total exposure period of six months. The tensile specimens and tensile blanks were used to determine the effect of corrosion on mechanical properties after an exposure time equal to the approximate time for stress corrosion failure, as well as after an exposure time of six months. Tensile specimens were machined from the tensile blanks. Other than wire brushing to remove corrosion products, the surfaces of the specimens were not altered after the corrosion exposure.

The results of these tests showed that the yield and tensile strengths of the steels, in either the stressed or unstressed condition, were not affected by corrosion during an exposure period equal to the approximate time for stress corrosion failure. In addition, the yield and tensile strengths of the steels, in the unstressed condition, were not affected by corrosion during an exposure period of six months. Because the severely corrosive environment at Kure Beach caused substantial corrosion on some of the steels during the six-month test, the cross-sectional area of the specimens measured after the exposure was used to calculate the mechanical properties.

The effect of corrosion on ductility, as measured by elongation in the tensile test, was also studied at Kure Beach. The results are shown in Table 6. The corrosion that occurred on either the stressed or unstressed specimens during an exposure time equal to the approximate time for stress-corrosion failure generally did not affect the ductility. 12 MoV stainless did exhibit a reduction in ductility on the stressed specimens. This reduction in ductility probably was caused by very small stress corrosion cracks on the specimens. The results of these tests showing that the mechanical properties of stressed specimens of the other steels were not affected by corrosion during an exposure time equal to the approximate time for stress corrosion failure are considered to be strong evidence that the stress corrosion process on these steels (and probably on 12 MoV stainless) consists of an induction period during which cracking does not occur, followed by a relatively short time period during which stress corrosion cracks are initiated and propagated through the specimens.

The ductility of the semiaustenitic precipitation-hardenable stainless steels was not affected by the six months exposure, but the loss in ductility observed on the other steels was appreciable. It is probable that the loss in ductility of the unstressed specimens exposed for six months was caused by the development of small corrosion pits that could act as stress

TABLE 2—Heat-Treatment and Mechanical Properties

Steel	HEAT-TREATMENT: Austenitizing or Conditioning, Temp, F	Austenitizing or Conditioning, Time	Tempering, Aging, or Refrigeration, Temp, F	Tempering, Aging, or Refrigeration, Time	MECHANICAL PROPERTIES: Yield Strength, psi	Tensile Strength, psi	Elongation in 2 in., Percent
USS Airsteel X200	1750	15 min	700	30 min	237,000	279,000	5.6
USS Strux	1750	15 min	700	30 min	230,000	266,000	5.0
MBMC No. 1	1700	15 min	575	2 hr	254,000	291,000	4.8
AISI 4340	1600	15 min	475	2 hr	218,000	261,000	6.0
AISI 4130	1600	15 min	800	30 min	157,000	166,000	7.0
AISI 4335+V	1625	15 min	500	2 hr	219,000	249,000	6.5
Hot-Work Die Steel, Type A (T1000)	1900	5 min	1000	4 hr	237,000	313,000	6.7
Hot-Work Die Steel, Type A (T1100)	1900	5 min	1100	4 hr	209,000	253,000	8.3
Hot-Work Die Steel, Type B (T1000)	1850	5 min	1000	4 hr	229,000	327,000	6.0
Hot-Work Die Steel, Type B (T1100)	1850	5 min	1100	4 hr	203,000	244,000	8.0
Hot-Work Die Steel, Type C (T1000)	1900	5 min	1000	4 hr	237,000	342,000	6.0
Hot-Work Die Steel, Type C (T1100)	1900	5 min	1100	4 hr	211,000	257,000	6.5
USS 12 MoV Stainless Steel	1850	15 min	900	4 hr	205,000	256,000	10.5
USS Stainless W	1900	15 min	1000	30 min	201,000	202,000	7.2
Precipitation-Hardenable Stainless, Type A (T1050)	1400	90 min	1050	90 min	154,000	192,000	8.7
Precipitation-Hardenable Stainless, Type A (T950)	1400	90 min	950	30 min	201,000	219,000	9.8
Precipitation-Hardenable Stainless, Type A (R950)	1750	10 min	− 100 950	8 hr 1 hr	203,000	225,000	8.7
Precipitation-Hardenable Stainless, Type B (T1050)	1400	90 min	1050	90 min	186,000	193,000	8.5
Precipitation-Hardenable Stainless, Type B (R950)	1750	10 min	− 100 950	8 hr 1 hr	202,000	229,000	9.0

Steel	TREATMENT: Reduction by Cold Rolling, Percent	Stress Relieving, Temp, F	Stress Relieving, Time	MECHANICAL PROPERTIES: Yield Strength, psi	Tensile Strength, psi	Elongation in 2 in., Percent
USS 17-5 MnV Stainless Steel	40	900	2 hr	236,000	256,000	....
USS 17-5 MnV Stainless Steel	40	1100	2 hr	236,000	243,000	7.0
USS 17-5 MnV Stainless Steel	60	800	2 hr	251,000	269,000	....
USS 17-5 MnV Stainless Steel	60	900	2 hr	260,000	277,000	1.8
USS 17-5 MnV Stainless Steel	60	1100	2 hr	264,000	279,000	4.0
USS TENELON Stainless Steel	60	800	2 hr	239,000	254,000	3.8
AISI Type 201 Stainless Steel	60	800	2 hr	229,000	253,000	1.2
AISI Type 202 Stainless Steel	60	800	2 hr	215,000	245,000	2.8
AISI Type 301 Stainless Steel	60	800	2 hr	238,000	249,000	3.0

TABLE 3—Results of Atmospheric Stress Corrosion Tests on Steels Exposed at the 80-Foot Lot, Kure Beach, N. C.*

Steel	Yield Strength, psi	NO. OF SPECIMENS		Average Time to Failure, days	UNFAILED SPECIMENS	
		Exposed	Failed		No.	Avg. Exposure Time, days
Alloy Steels						
USS Airsteel X200	237,000	24	24	11	..	...
USS Strux	230,000	5	5	6	..	...
MBMC No. 1	254,000	6	6	7	..	...
AISI 4340	218,000	3	3	10	..	...
AISI 4130	157,000	6	0	..	6	175
Martensitic Stainless Steels						
Hot-Work Die Steel (T1000)	229,000 to 237,000	21	21	4	..	...
Hot-Work Die Steel (T1100)	203,000 to 211,000	18	3	250	15	750
USS 12 MoV Stainless	205,000	40	40	1	..	...
Semiaustenitic Precipitation-Hardenable Stainless Steels						
USS Stainless W	201,000	12	12	47	..	...
Precipitation-Hardenable Stainless, Type A (T1050)	154,000	27	7	21	20	320
Precipitation-Hardenable Stainless, Type A (T950)	201,000	4	4	1	..	...
Precipitation-Hardenable Stainless, Type A (R950)	203,000	30	21	5	9	380
Precipitation-Hardenable Stainless, Type B (T1050)	186,000	12	9	16	3	240
Precipitation-Hardenable Stainless, Type B (R950)	202,000	12	12	16	..	...
Cold-Worked and Stress-Relieved Austenitic Stainless Steels						
USS 17-5 MnV	236,000 to 264,000	15	..	...	15	370
USS TENELON	239,000	6	..	...	6	240
AISI Type 201 Stainless Steel	229,000	6	..	...	6	240
AISI Type 202 Stainless Steel	215,000	6	..	...	6	240
AISI Type 301 Stainless Steel	238,000	6	..	...	6	240

* Stress Level: 75 Percent Yield Strength.

TABLE 4—Results of Atmospheric Stress Corrosion Tests on Steels Exposed at Monroeville, Pa.*

Steel	Yield Strength, psi	NO. OF SPECIMENS		Avg. Time to Failure, days	UNFAILED SPECIMENS	
		Exposed	Failed		No.	Avg. Exposure Time, days
Alloy Steels						
USS Airsteel X200	237,000	5	5	205	..	...
USS Strux	230,000	5	5	21	..	...
Martensitic Stainless Steels						
Hot-Work Die Steel, Type A (T1000)	237,000	4	4	10	..	...
USS 12 MoV Stainless	205,000	45	45	5	..	...
Semiaustentic Precipitation-Hardenable Stainless Steels						
USS Stainless W	201,000	7	..	...	7	520
Type A (T1050)	154,000	7	..	...	7	520
Type A (R950)	203,000	7	..	...	7	520

*Stress Level: 75 Percent Yield Strength.

raisers on the surface of the specimens. Approximately the same mechanical properties were observed on the tensile specimens after corrosion and on the tensile specimens machined from tensile blanks after corrosion. This result indicates that edge attack did not have an appreciable effect on the mechanical properties.

Effect of Coatings

The results of the above tests show that high-strength aircraft and missile steels can be susceptible to stress corrosion cracking in marine and semi-industrial atmospheres. The use of protective coatings is one possible way of preventing this type of corrosion. Therefore, a program was undertaken to study the protective effects of the various coatings listed in Table 7.

The steels used to evaluate the coatings were 12 MoV stainless steel, tempered at 900 F, and hot-work die steel, Type A, tempered at 1000 F. Bent-beam specimens from these two steels were prepared as described previously. After the specimens were prepared but before they were stressed, the various coatings were applied, with the exception of aluminum, aluminum-pigmented silicone, and rust-preventive wax and grease. One group of aluminum and aluminum-pigmented silicone coatings was applied before the austenitizing treatment; the other group was applied after austenitizing but before tempering. The rust-preventive wax and grease were applied after stressing at the time the specimens were installed on the racks. The surface-preparation steps preceded the coating operation regardless of the heat-treatment cycle. The thickness of each specimen was measured before and after coating, and an average coating thickness calculated, Table 7.

The coatings were evaluated in the unscratched condition and with a scratch to simulate possible damage to the coating. One scratch approximately 2 inches long was made on the tension side with a pointed steel tool parallel to the long edge at the center of the specimen. The stress level used was 75 percent of the yield strength. The tests were conducted at Kure Beach, and at Monroeville. For the two steels at each location, two scratched specimens and two unscratched specimens were exposed for most of the coatings.

The time to failure is given in Table 8 for the Kure Beach specimens and in Table 9 for the Monroeville specimens. The uncoated control specimens of 12 MoV stainless and the hot-work die steel failed in an average of 0.7 day and 2.4 days, respectively, in the severe marine atmosphere at Kure Beach. In the milder atmosphere at Monroeville, the uncoated specimens of 12 MoV stainless and the hot-work die steel failed in an average of 4 days and 10 days, respectively.

At Kure Beach, aluminum applied after austenitizing prevented cracking of both steels for the total exposure period of 420 days. In addition, only one stressed specimen of eight, coated with nickel-cadmium electroplate, failed (in 263 days) at this location. Two specimens of eight coated with zinc-dust dibutyl titanate primer failed after 395 and 400 days, respectively. On both specimens, the fracture occurred near one end of the specimen in an area where the coating had peeled off and considerable rusting had taken place. Aluminum applied before austenitizing and the aluminum-pigmented silicone coating applied after austenitizing were effective on some of the specimens at Kure Beach; however, relatively short-term failures were also obtained with these coatings.

At Monroeville, cracking of the two steels was prevented by aluminum applied after austenitizing, zinc-dust dibutyl titanate primer, nickel-cadmium electroplate, and rust-preventive wax. The zinc chromate - iron oxide alkyd paint and rust-preventive grease were also effective

in delaying cracking at this location. Although relatively long-term failures occurred with the specimens coated with one type of zinc chromate primer, relatively short-term failures were observed with another type of zinc chromate primer that met the requirements of Military Specification MIL-P-6889A, Type I. The reason for this difference in performance is not known. At both locations, the performance of scratched specimens was approximately the same as that of unscratched specimens.

The electrode potential of uncoated 12 MoV stainless steel and hot-work die steel, as well as the electrode potential of the same steels coated with various products, was measured to determine whether there is any correlation between the electrode potential of coatings and their ability to prevent stress corrosion. An aerated 3 percent sodium chloride solution was used as an electrolyte, and all measurements were made with reference to a saturated calomel electrode.

It was found that the coatings that are very effective in delaying stress corrosion (zinc-dust dibutyl titanate primer, sprayed aluminum, and nickel-cadmium electroplate) are anodic to both of the steels. The following coatings did not prevent cracking and were found to be cathodic to the underlying steel: electroplated chromium on both steels, electroplated nickel and electroless nickel on the hot-work die steel, and electroless nickel on 12 MoV stainless steel. These results indicate that anodic coatings prevent cracking and cathodic coatings do not prevent cracking. Electroplated nickel on 12 MoV represents an exception to this generalization. This coating was cathodic to 12 MoV and yet delayed stress corrosion at both exposure locations.

The electrical resistance of the zinc-dust dibutyl titanate primer, measured with a Wheatstone bridge, was found to be very high, about 10,000,000 ohms. This high resistance indicates that the zinc particles in this coating are not in electrical contact with each other. Therefore, electrical contact between the zinc particles does not appear necessary for this coating to prevent atmospheric stress corrosion. Apparently, the zinc particles in direct contact with the steel are sufficient to cathodically protect the steel in the presence of water or salt water that penetrates the coating.

In summarizing, the results of these tests on coatings show that certain protective coatings represent a very promising method of preventing stress corrosion cracking of aircraft and missile steels. Any specific applications should be further evaluated because these specimen tests are only an indication of the protective value of the coatings.

Effect of Tempering Temperature

The effect of tempering temperature on the atmospheric stress corrosion resistance of 12 MoV stainless steel and Airsteel X200 was determined in tests conducted at Kure Beach. Laboratory tests were also conducted in an aerated 3 percent sodium chloride solution at room temperature The mechanical properties of the two steels in the untempered condition and after tempering at temperatures from 400 to 1200 F are shown in Table 10.

Three specimens of each steel in each temper were used in the tests at Kure Beach and in the laboratory tests. The Kure Beach tests were continued for 1 year and the laboratory tests were continued for 40 days. The specimens were exposed at a stress level of 75 percent of the yield strength. Because untempered Airsteel X200 broke before reaching maximum load, this steel in the untempered condition was stressed to 75 percent of the observed tensile strength. The specimen holders used in the laboratory tests were made of plastic to eliminate any galvanic effects between the holders and the specimens.

TABLE 5—Effect of Stress Level on Stress Corrosion of Aircraft Steels*

Steel	Yield Strength, psi	TIME TO FAILURE, DAYS**		
		50%***	75%***	90%***
USS Airsteel X200	237,000	6	6	8
AISI 4340	218,000	12	10	8
MBMC No. 1 (Longitudinal)	254,000	28	5	7
MBMC No. 1 (Transverse)	257,000	16	8	5
AISI 4335+V (Longitudinal)	219,000	NF	NF	NF
AISI 4335+V (Transverse)	257,000	NF	25	15
Hot-Work Die Steel, Type A	239,000	6	9	8
USS 12 MoV Stainless	205,000	1.4	1	1
USS Stainless W	201,000	65	11	22
Precipitation-Hardenable Stainless, Type A (T950)	201,000	5	1	1
Precipitation-Hardenable Stainless, Type A (R950)	203,000	16	5	2
Precipitation-Hardenable Stainless, Type B (R950)	202,000	NF	15	12

NF = No failure in 175 days.
* Exposure at the 80-foot lot, Kure Beach.
** Average of three specimens or more.
*** Stress levels are given in terms of percent of yield strength.

TABLE 6—Effect of Corrosion on Ductility*

Steel	Approximate Exposure Time, days	ELONGATION IN 2 INCHES, PERCENT			
		Before Exposure	After Corrosion for Approximate Exposure Time		After Corrosion for 6 Months
			Unstressed	Stressed	Unstressed
AISI 4340	10	6.0	5.2	5.5	1.7
Hot-Work Die Steel, Type A (T1000)	8	5.5	5.7	6.1	1.3
USS 12 MoV Stainless	1	10.2	9.2	4.7	2.1
USS Stainless W	34	5.7	4.1	5.2	4.1
Precipitation-Hardenable Stainless Steel, Type A (R950)	8	8.7	7.5	6.9	5.8
Precipitation-Hardenable Stainless Steel, Type B (R950)	13	9.0	7.3	6.0	6.9

* Exposure at 80-foot lot, Kure Beach.

TABLE 7—Coatings Tested

Coating	Description	Measured Average Thickness, Inch
Ni-Cd electroplate	Specification AMS 2416; electroplated Ni 0.002 to 0.0004 in., followed by electroplated Cd 0.0001 to 0.0002 in., followed by diffusion at 630 F for 1 hr.	0.0005
Electroless Ni	Coated to 0.002-in. thickness, followed by postbaking heat-treatment.	0.0017
Electroplated Ni	"Gray Nickel" plate.	0.0025*
Chromium	Commercial electroplating	0.0013
Aluminum	Al-metallizing, followed by dip coating with hydrolyzed ethyl silicate.	0.0057
Al-pigmented silicone	Baked 2 hr. at 425 F.	0.0013
Silicone	Baked 2 hr. 450 F.	0.0005
Zinc chromate iron oxide alkyd paint	Primed and painted, air-dried.	0.0019
Zinc chromate primer	Air-dried	0.0009
Zinc-dust dibutyl titanate	An experimental zinc-dust dibutyl titanate primer, air-dried.	0.0021
Rust-preventive wax	Coating was applied to stressed specimens immediately before exposure.	0.0012
Rust-preventive grease	Coating was applied to stressed specimens immediately before exposure.	Not measured
Strontium chromate aluminum paint	Air-dried	0.0008
Aircraft-type zinc chromate primer	Specification: MIL-P-6889A Type I, air-dried.	0.0002

* Coating peeled off during stressing on some specimens. These specimens were excluded from the test.

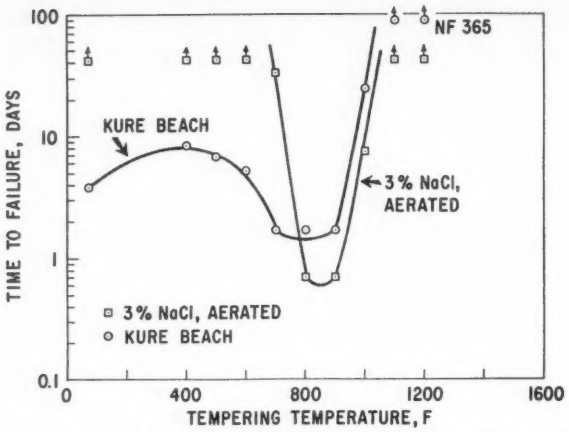


Figure 4—Effect of tempering temperature on stress corrosion of USS 12 MoV stainless steel.

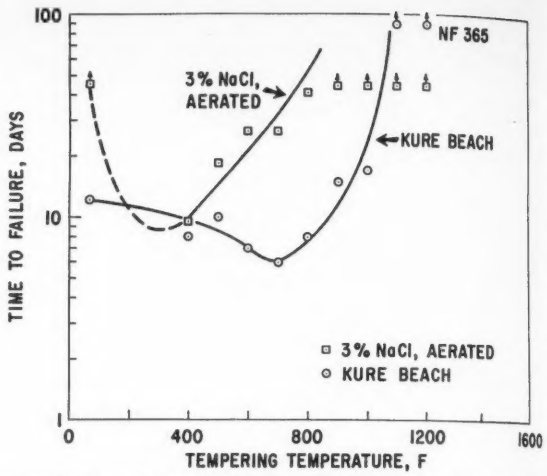


Figure 5—Effect of tempering temperature on stress corrosion of Airsteel X200.

TABLE 8—Effect of Protective Coatings on Stress Corrosion of Aircraft Alloys*

Coating	TIME TO FAILURE, DAYS	
	12 MoV	Die Steel
No Coating	0.7	1.5 to 3
Coatings That Prevented Stress Corrosion		
Aluminum applied after austenitizing	NF	NF
Coatings That Delayed Stress Corrosion		
Ni-Cd electroplate	NF	263**
Zinc-dust dibutyl titanate	NF	395**
Aluminum applied before austenitizing	4 to 66	46**
Al-pigmented silicone applied after austenitizing	7**	147**
Aircraft-type zinc chromate primer	2 to 17	.....
Electroplated Ni	405**	0.7
Coatings With No Appreciable Effect on Stress Corrosion		
Electroless Ni	0.7	0.7 to 1
Electroplated Cr	0.7	0.01 to 4
Al-pigmented silicone applied before austenitizing	0.7	2 to 3
Silicone	0.7	0.7 to 5
Zinc chromate iron oxide alkyd paint	0.7 to 3	0.7 to 13
Zinc chromate primer	0.7 to 1	.....
Rust-preventive wax	0.7 to 13	0.7 to 4
Rust-preventive grease	0.7 to 3	0.7 to 5
Strontium chromate aluminum paint	0.7 to 1	.....

NF = No failure in 420 days.
* Results of exposure at Kure Beach, N. C.
** Some specimens have not failed after 420 days.

The effect of tempering temperature on the stress corrosion behavior of 12 MoV stainless and Airsteel X200 is shown in Figures 4 and 5, respectively. The results of the tests on 12 MoV stainless indicate that this steel, when tempered at temperatures of 1100 and 1200 F, is resistant to stress corrosion cracking. Tempering of this steel at temperatures of 800 and 900 F results in the shortest time to failure.

A surprising difference between the results of the laboratory tests and the Kure Beach tests was observed with untempered 12 MoV stainless and this steel tempered at 400, 500, and 600 F. Failures did not occur in 40 days in the laboratory tests, whereas failures occured in less than 10 days in the Kure Beach tests.

In the immersion tests, the whole specimen was immersed in the conducting solution so that anodic activity on one portion of the specimen (for example, in the crevice formed where the specimen touches the holder) could influence the stress corrosion process in the center of the specimen where the stress is highest. In the atmospheric tests, it is believed that corrosion occurs under small water droplets so that a similar influence of one portion of the specimen on another portion would not be expected. The results of the Kure Beach tests show that sensitivity to stress corrosion cracking exists in the untempered condition and is not appreciably modified by tempering at temperatures of from 400 to 900 F.

The results of the test on Airsteel X200 show that this steel when tempered at 1100 and 1200 F is also resistant to stress corrosion cracking. Here again, a difference was observed in the results of the laboratory tests and the Kure Beach tests. This steel when untempered and when tempered at temperatures of 900 and 1000 F did not fail in 40 days in the laboratory tests but did fail in less than 20 days in the Kure Beach tests. The results of the Kure Beach tests show that Airsteel X200 is also sensitive to stress corrosion cracking in the untempered condition and that the sensitivity is not appreciably modified by tempering at temperatures of from 400 to 1000 F (although it is when tempered at 1100 and 1200 F).

Studies on the Mechanism of Stress Corrosion

Laboratory humidity tests were conducted to determine whether exposure to a corrosive environment was the cause of cracking that had occurred in the atmospheric tests. The studies were conducted with 12 MoV stainless tempered at 900 F. Bent-beam specimens of this steel stressed at 75 percent of the yield strength were sprayed with a mist of 3 percent sodium chloride solution and exposed at room temperature to (1) air in the laboratory, (2) dry air in a desiccator, and (3) air saturated with moisture in a closed container. Specimens exposed to condition (3) failed in very short times, as shown in Table 11. Specimens exposed to condition (2) have not failed in 400 days. The specimens exposed to laboratory air failed in times ranging from 169 to 197 days. These latter failures coincided with the approach of summer and humid weather. The results of these laboratory tests show that the environment is one of the controlling factors in the failures observed.

Laboratory immersion tests were conducted to determine whether anions other than chloride would cause cracking of 12 MoV stainless. Most of these tests were conducted with U-bend specimens at high but unknown stress levels. The results, Table 11, show that several of the anions tested caused cracking of 12 MoV stainless. It was found also that several of the solutions did not cause cracking in 500 to 600 hours of test, again an indication that the environment is one of the controlling factors in the failures observed on this steel.

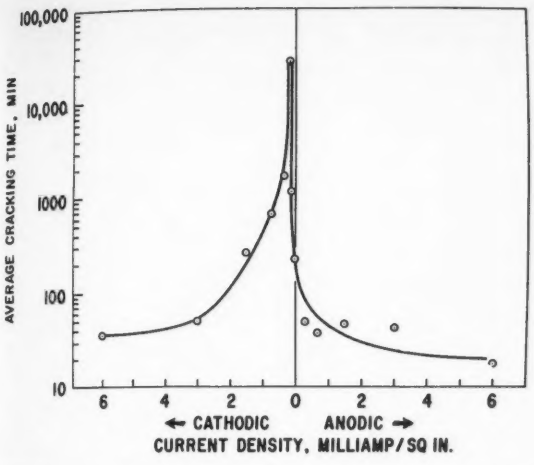


Figure 6—Effect of applied current on cracking time, USS 12 MoV stainless steel in aerated 3 percent NaCl solution.

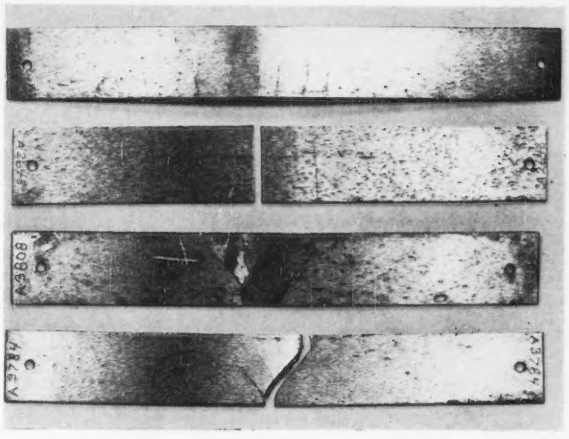


Figure 7—Appearance of failed stress corrosion specimens. Top specimen, 12 MoV stainless; second specimen, 12 MoV stainless; third specimen, precipitation-hardenable stainless, Type B (R950); bottom specimen, precipitation-hardenable stainless, Type A (R950).

In the results presented thus far, it has been shown that very high strength steels can be susceptible to stress corrosion cracking when stressed and simultaneously exposed to a corrosive environment. Two possible mechanisms for this type of failure are (1) localized corrosion along a continuous active path through the steel, or (2) general corrosion of metal accompanied by hydrogen formation and hydrogen penetration into the metal that could lead to a "hydrogen embrittlement" type of failure. Mechanism (1) would indicate that the anodic reaction on the metal surface is the dominant reaction. Mechanism (2) would indicate that the cathodic reaction on the metal surface is the dominant reaction.

To distinguish between these two mechanisms, experiments were conducted on one of the susceptible steels, 12 MoV stainless tempered at 800 F. The experiments consisted of observing the effect of anodic and cathodic polarization on the time to failure of stressed specimens exposed to an aerated solution of 3 percent sodium chloride at room temperature.

Six specimens were used to determine the time to failure. Each specimen was placed in a separate beaker with a platinum electrode. The specimens were prepared as previously described, and the stress level used was 75 percent of the yield strength. Plastic specimen holders were used, and the electrical connection to the specimen was waxed to prevent contact with the solution. An external resistance was used to adjust the current from a set of batteries to the appropriate current density. In each experiment, the platinum electrodes and the specimens in each of the six beakers were connected in series so that the same current density would be applied to each specimen.

The effect of anodic and cathodic polarization on the average cracking time is shown in Figure 6. Anodic polarization reduced the time to failure from 200 minutes with no applied current to 20 minutes at a current density of 6 milliamperes per square inch (ma/in²).

TABLE 9—Effect of Protective Coatings on Stress Corrosion of Aircraft Alloys*

Coating	TIME TO FAILURE, DAYS	
	12 MoV	Die Steel
No Coating	4	4 to 20
Coatings That Prevented Stress Corrosion		
Ni-Cd electroplate	NF	NF
Aluminum applied after austenitizing	NF	NF
Zinc-dust dibutyl titanate	NF	NF
Rust-preventive wax	NF	NF
Coatings That Delayed Stress Corrosion		
Aluminum applied before austenitizing	4 to 7	18**
Al-pigmented silicone applied before austenitizing	7 to 10	22**
Al-pigmented silicone applied after austenitizing	7 to 26	25**
Silicone	15**	10 to 22
Zinc chromate iron oxide alkyd paint	319**	69**
Rust-preventive grease	324**	285 to 359
Zinc chromate primer	146 to 324	.....
Strontium chromate aluminum paint	6 to 21	.....
Aircraft-type zinc chromate primer	6 to 364	.....
Electroplated Ni	319**	4 to 7
Coatings With No Appreciable Effect on Stress Corrosion		
Electroless Ni	4	4 to 15
Electroplated Cr	0.7 to 4	0.0007 to 4

NF = No failure in 420 days.
* Results of exposure at Monroeville, Pa.
** Some specimens have not failed in 420 days.

With low cathodic current densities, the time to failure was greatly extended (about 27,000 minutes at 0.137 ma/in²). At cathodic current densities higher than 0.137 ma/in², the time to failure became progressively shorter. The time to failure was 10 minutes at a cathodic current density of 6 ma/in².

This behavior indicates that with no current, with anodic polarization, and with cathodic polarization at low current densities, the observed cracking is caused by corrosion along an active path through the steel. At cathodic current densities higher than 0.137 ma/in², hydrogen embrittlement is the probable cause of the cracking.

Appearance of Stress Corrosion Cracks and Metallographic Studies

The appearance of some cracked specimens from the atmospheric tests at Kure Beach is shown in Figure 7. Stain and corrosion products have not been removed from these specimens. Generally, cracks in the alloy steels, hot-work die steels, and 12 percent chromium steels progressed along a line perpendicular to the direction of the applied stress. However, cracks in the semiaustenitic precipitation-hardenable stainless steels usually progressed at an angle to the applied stress, as can be seen in the bottom specimen of Figure 7. The initiation of cracks was more prevalent on the edges of the specimens than away from the edges. After initiation, the cracks usually progressed relatively slowly. Very rapid propagation of the cracks was noted with some of the 0.050-inch-thick specimens of 12 MoV stainless, but was not noted with 0.020-inch-thick specimens. The second specimen from the top in Figure 7 shows the appearance of a specimen on

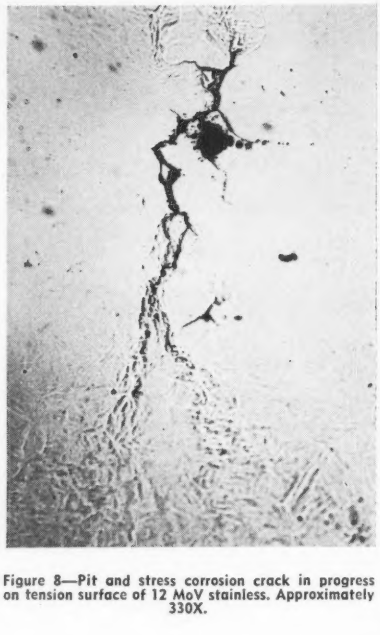


Figure 8—Pit and stress corrosion crack in progress on tension surface of 12 MoV stainless. Approximately 330X.

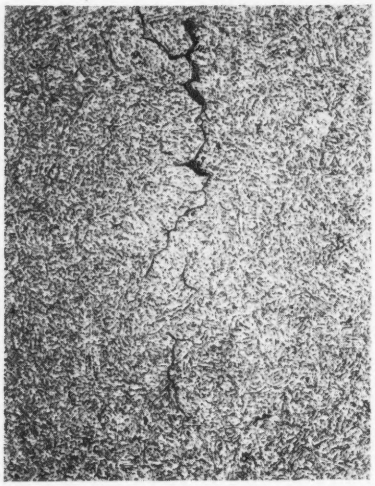


Figure 9—Appearance of stress corrosion crack in Airsteel X200. Super picral etch, approximately 290X.

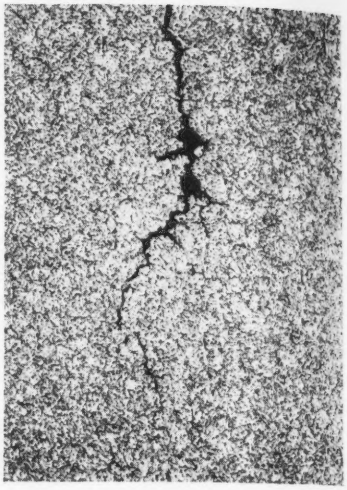


Figure 10—Appearance of stress corrosion crack in hot-work die steel, Type A. Super picral etch, approximately 290X.

which very rapid crack propagation occurred. When very rapid propagation was obtained, it is probable that a small stress corrosion crack at the edge of the specimen initiated a brittle fracture.

Figure 8 shows the appearence of a pit and a stress corrosion crack in progress on the tension surface of 12 MoV stainless. A miniature bent-beam specimen sprayed with a fine mist of NaCl was used to obtain this photomicrograph. The wavy-appearing structure ahead of each end of the crack could not be brought clearly into focus. This curious structure may be the result of stress corrosion cracks progressing underneath the surface.

The microstructure and the appearance of stress corrosion cracks in several steels are shown in Figures 9 through 12. These photomicrographs were obtained by polishing the surfaces of the specimens that had been in tension. The appearance of cross sections was similiar to these surface sections. With these hardened steels, it is difficult to determine whether the cracks are intergranular or transgranular because it is difficult to etch the steels to clearly show the grain boundaries. In general, the results of metallographic studies indicate that the cracks are intergranular with respect to the prior austenite grain boundaries.

The appearance of cracks in specimens used in the laboratory studies to determine the effect of anodic and cathodic polarization is shown in Figure 13. Some branching was observed with no applied current and with anodic polarization, but no branching was observed with cathodic polarization. Also, more cracks were present on the surface of the specimen that was polarized anodically.

Studies are in progress with the electron microscope to determine the microstructural characteristics of the high-strength steels included in this work. To

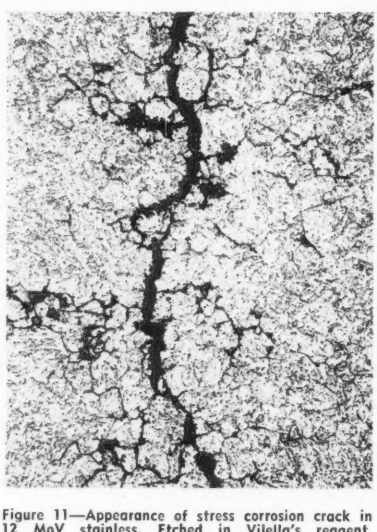


Figure 11—Appearance of stress corrosion crack in 12 MoV stainless. Etched in Vilella's reagent, approximately 290X.

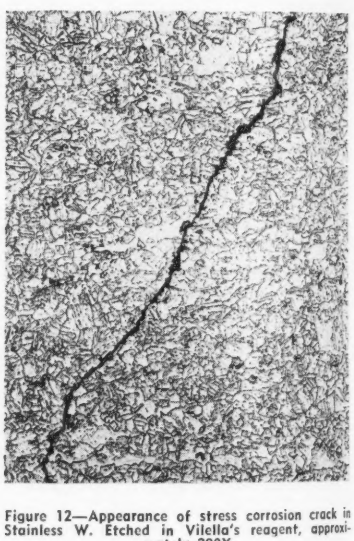


Figure 12—Appearance of stress corrosion crack in Stainless W. Etched in Vilella's reagent, approximately 290X

TABLE 10—Effect of Tempering Temperature on Mechanical Properties

Tempering Temperature, F	Material Tested	Yield Strength, psi	Tensile Strength, psi	Elongation in 2 in., Percent
None	USS 12MoV[1]	189,000	253,000	2.0
400	USS 12MoV[1]	192,000	254,000	5.8
500	USS 12MoV[1]	187,000	248,000	6.0
600	USS 12MoV[1]	190,000	247,000	4.0
700	USS 12MoV[1]	191,000	250,000	4.5
800	USS 12MoV[1]	207,000	256,000	7.5
900	USS 12MoV[1]	205,000	258,000	8.8
1000	USS 12MoV[1]	156,000	190,000	6.0
1100	USS 12MoV[1]	133,000	159,000	5.5
1200	USS 12MoV[1]	133,000	157,000	8.2
None	USS Airsteel X200[2]	*	162,000	*
400	USS Airsteel X200[2]	214,000	313,000	9.0
500	USS Airsteel X200[2]	236,000	297,000	7.2
600	USS Airsteel X200[2]	239,000	291,000	6.8
700	USS Airsteel X200[2]	242,000	288,000	7.0
800	USS Airsteel X200[2]	225,000	271,000	10.0
900	USS Airsteel X200[2]	190,000	260,000	8.5
1000	USS Airsteel X200[2]	201,000	238,000	7.2
1100	USS Airsteel X200[2]	191,000	214,000	9.5
1200	USS Airsteel X200[2]	159,000	181,000	11.5

* Broke before reaching maximum load.
[1] Austenitized at 1850 F for 15 minutes and tempered for 4 hours.
[2] Austenitized at 1750 F for 15 minutes and tempered for ½ hour.

date, these studies have not indicated any microstructural characteristics that can be correlated with stress corrosion behavior. Electron photomicrographs of Airsteel X200 tempered at 600 F and tempered at 1200 F are shown in Figure 14. From these electron photomicrographs, the reason is not evident why this steel when tempered at 600 F is susceptible to stress corrosion and when tempered at 1200 F is not susceptible to stress corrosion.

Summary and Discussion

1. Steels heat-treated to very high strength can be susceptible to atmospheric stress corrosion in the severely corrosive environment at Kure Beach, North Carolina. Some steels can also be susceptible in the moderately corrosive semi-industrial environment at Monroeville, Pennsylvania.

2. Cold-worked and stress-relieved austenitic stainless steels have very high yield and tensile strengths and are resistant to atmospheric stress corrosion at Kure Beach. The semiaustenitic precipitation-hardenable stainless steels are resistant to atmospheric stress corrosion at Monroeville.

3. Generally, the time to failure for the susceptible steels increased when the stress level was decreased from 90 percent to 50 percent of the yield strength. Some steels, however, exhibited about the same failure time at stress levels of 50, 75, and 90 percent of the yield strength.

4. The yield and tensile strengths of several steels were not affected by corrosion during six months exposure at Kure Beach. The ductility of steels containing 12 percent chromium or less was decreased by this exposure.

5. When environmental conditions dictate, atmospheric stress corrosion cracking of aircraft and missile steels can be prevented by the application of certain protective coatings.

6. An alloy steel and a 12 percent chromium martensitic stainless steel were not susceptible to stress corrosion when they were tempered at 1100 and 1200 F. The stress corrosion resistance of hot-work die steels tempered at 1100 F was much greater than when these steels were tempered at 1000 F.

7. The results of laboratory tests show that the environment is one of the controlling factors in failures observed on a 12 percent chromium martensitic stainless steel and that anions other than chloride can cause cracking.

8. The results of experiments on the mechanism of cracking indicate that stress corrosion of a 12 percent chromium martensitic stainless steel is the result of corrosion along an active path in the steel and is not the result of hydrogen induced in the metal by corrosion.

A correlation between the specimen tests presented in this paper and service performance has not been established. The test results should be regarded as a guide to effective utilization of steels in

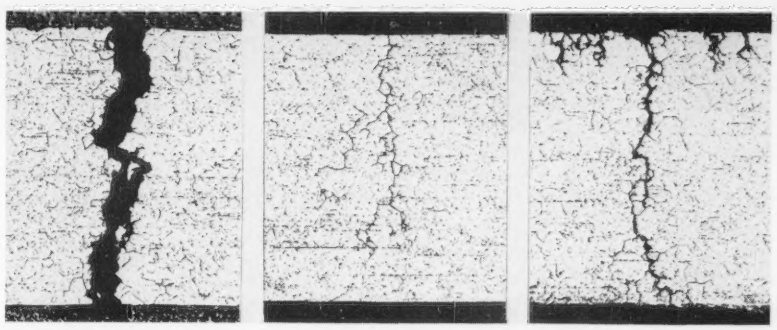


Figure 13—Appearance of cracks in USS 12 MoV stainless exposed to 3 percent NaCl solutuion. Left, cathodic current; center, no applied current; right, anodic current. Etched electrolytically in 10 percent ammonium persulfate, approximately 185X.

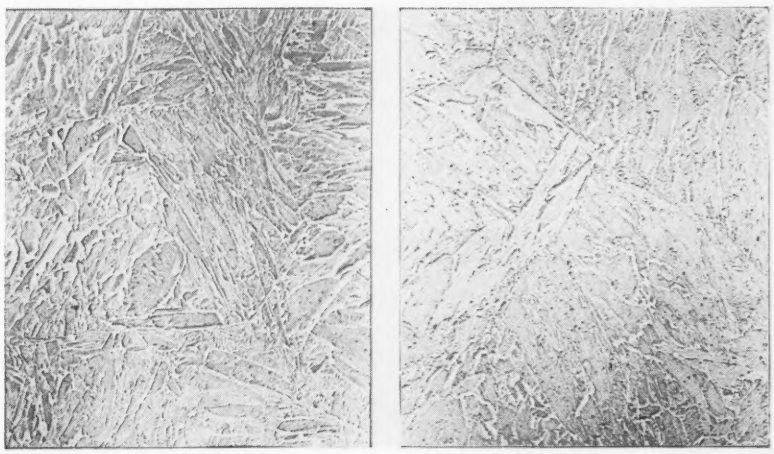


Figure 14—Electron photomicrographs of Airsteel X200 tempered at 600 F (left) and 1200 F (right). Picral etch, approximately 6000X.

TABLE 11—Effect of Environment on Stress Corrosion of USS 12 MoV Stainless Steel

Type of Specimen	Environment	Results
Humidity Tests		
Bent Beam	Specimens sprayed with fine mist of 3 percent sodium chloride solution and exposed to air saturated with water.	Failure in 8 hr.
Bent Beam	Specimens sprayed with fine mist of 3 percent sodium chloride solution and exposed to laboratory air.	Failure in 169 to 197 days.
Bent Beam	Specimens sprayed with fine mist of 3 percent sodium chloride solution and exposed to dry air in a desiccator.	No failure in 400 days.
Immersion Tests in Aerated Solutions		
Bent Beam	Sodium chloride (3%)	Failure in 4 hr.
U-Bend	Sodium chloride (1M)	Failure in 10 to 60 min.
U-Bend	Sodium chloride (3%, boiling)	Failure in 2 to 24 min.
U-Bend	Sodium iodide (1M)	Failure in 3 to 10 min.
U-Bend	Sodium bromide (1M)	Failure in 9 to 12 min.
U-Bend	Sodium fluoride (1M)	Failure in 15 to 25 min.
U-Bend.	Magnesium chloride (42%, boiling)	Failure in ½ to 2 min.
U-Bend	Sodium phosphate, monobasic (1M)	Failure in 5 min.
U-Bend	Sodium phosphate, tribasic (saturated)	Failure in 50 to 75 min.
U-Bend	Sodium sulfate (1M)	Failure in 4 to 5 min.
U-Bend	Hydrogen sulfide (saturated)	Failure in 10 to 40 min.
U-Bend	Sodium sulfite (1M)	Failure in 28 to 93 hr.
U-Bend	Sodium nitrate (1M)	Failure in 17 to 22 hr.
U-Bend	Sodium chlorate (1M)	Failure in 21 to 500 hr.
U-Bend	Sodium cyanide (1M)	No failure in 600 hr.
U-Bend	Sodium nitrite (1M)	No failure in 600 hr.
U-Bend	Sodium hydroxide (1M)	No failure in 600 hr.
U-Bend	Sodium bicarbonate (1M)	No failure in 600 hr.
U-Bend	Sodium acetate (1M)	No failure in 500 hr.

aircraft and missile applications, but they should not be regarded as a direct indication of expected service performance.

In using very high strength steels for aircraft and missile applications where stress and exposure to a corrosive environment are involved, the possibility of stress corrosion cracking should be considered. In missile applications, corrosive environments could include fabricating-plant atmospheres, hydrostatic-test media, storage atmospheres, and propellants and fumes from propellants. In aircraft applications, corrosive environments could include fabricating-plant atmospheres, the many different atmospheres to which an aircraft might be exposed at various landing fields, and exhaust deposits from jet engines and rockets.

The applied stress on an aircraft or missile component during exposure to these environments probably would not approach the designed operating stress. However, residual stresses can be introduced into any part by welding, mechanical joining, forming operations, and heat-treatment. These residual stresses when high and in tension are as damaging as high applied stresses from the standpoint of stress corrosion. It is the net tensile stress, residual and applied, thats affects the stress corrosion process.

The use of certain protective coatings is a very promising method of preventing stress corrosion cracking of very high strength steels for use in aircraft and missile applications. Although the results on coatings contained in this paper can be used as a guide, any specific application should be evaluated by service tests.

In applications where very high strength is not required, the use of a high tempering temperature to reduce or eliminate susceptibility to stress corrosion should be considered. The cold-worked and stress-relieved austenitic stainless steels are very promising materials for applications where very high strength and resistance to stress corrosion are required.

Acknowledgment

The authors express their appreciation to H. J. Bhatt, who assisted in carrying out the atmospheric tests and conducted the laboratory experiments in which the effect of anodic and cathodic polarization on stress corrosion was studied.

References

1. A. E. Durkin. *Metal Progress*, 64, 72-74 (1953).
2. W. L. Badger. *SAE Transactions*, 62, 307-313 (1954).
3. P. Lillys and A. E. Nehrenberg. *Trans. ASM*, 48, 327-355 (1956).
4. F. K. Bloom. *Corrosion*, 11, 351t-361t (1955).
5. J. Halbig and O. B. Ellis. *Corrosion*, 14, 389t-395t (1958).
6. B. F. Brown. *Corrosion*, 15, 399t-402t (1959).
7. M. E. Shank, C. E. Spaeth, V. W. Cooke, and J. E. Coyne. *Metal Progress*, 76, 74-82 (1959).
8. G. F. Sager, R. H. Brown, and R. B. Mears. Symposium on Stress Corrosion Cracking of Metals, ASTM-AIME, 1944, p. 258.

DISCUSSION

Question by Donald Warren, Engineering Research Laboratory, E. I. duPont de Nemours & Co., Wilmington, Delaware:

The author said that some of the unfailed test specimens at the Kure Beach Lot showed a loss in ductility as compared to unexposed test specimens. Was this loss in ductility caused by a reduction in effective cross-sectional area (due to localized or general attack) or was it caused by hydrogen embrittlement (due to hydrogen charged into the steel by corrosive attack)?

Reply by E. H. Phelps and A. W. Loginow:

The loss of ductility of unfailed stressed specimens and unstressed specimens exposed for six months at Kure Beach was attributed to the development of corrosion pits, which could act as stress raisers. However, it is also possible that hydrogen charged into the steel by corrosive attack was a factor in the observed loss in ductility. The former explanation of the ductility results was used because any hydrogen charged into the specimens during corrosion would tend to discharge during the time period between their removal from the corrosive atmosphere and tensile testing (3 to 5 weeks). To resolve this question, an additional exposure is planned in which the hydrogen will be removed by baking the corroded specimens prior to tensile testing.

Question by Franklin H. Beck, Engineering Experiment Station, Ohio State University, Columbus, Ohio:

Is there any influence of either surface finish or chemistry of alloy (as chemistry variation between different heats of 12 percent Cr alloy) on time for failure in your atmospheric exposure tests?

Reply by E. H. Phelps and A. W. Loginow:

The stress-corrosion behavior of different heats of 12 MoV stainless, with minor variations in composition, was approximately the same. In a test to evaluate two types of surface finish, specimens of 12 MoV stainless, stainless "W", and semiaustenitic precipitation-hardenable stainless, Type A, were prepared by grinding and by pickling in a mixture of nitric acid and hydrofluoric acid. For each of the steels tested, the time to failure of the ground specimens was approximately the same as that of the pickled specimens.

Questions by Norman D. Groves, Carpenter Steel Company, Reading, Pa.:

How do you load your specimens to eliminate or prevent "over stressing?" Have you exposed any of the austenitic stainless steels in the cold worked condition without stress relieving?

Reply by E. H. Phelps and A. W. Loginow:

Care was taken to minimize any overstressing of the specimens. When the specimens were bent by hand, one end of the specimen was placed in one groove of the holder and the specimen was bent until the other end of the specimen slipped into the other groove. White cotton gloves were used when the specimens were bent by hand. With some of the thicker specimens, however, it was necessary to use a mechanical four-point loading device. With this device, the specimens could be bent until they fitted the holders.

Cold-rolled austenitic stainless steels in the non-stress-relieved condition were not included in the tests reported in the paper. However, in a previous test conducted at the 80-foot lot at Kure Beach, AISI Type 301 stainless in the ½-hard condition was exposed at a stress level of 75 percent of the yield strength. No failure was observed in 60 months exposure.

Questions by Charles E. Fox, Dowell Division, Dow Chemical Company, Tulsa, Oklahoma:

What is appearance of specimens that have not failed? Can you correlate corrosion to cracking?

Reply by E. H. Phelps and A. W. Loginow:

Depending on the exposure time and location, the appearance of unfailed specimens ranged from general corrosion and rusting on the alloy steels and on the hot-work die steels, to slight, moderate, or heavy staining with some pitting (at Kure Beach) on the steels containing 12 percent chromium or more. In these atmospheric tests, susceptibility to cracking did not correlate with general corrosion resistance.

Discussion by M. E. Shank, MIT, Cambridge, Mass., and C. E. Spaeth, V. W. Cooke, and J. E. Coyne, Pratt and Whitney Aircraft Co., East Hartford, Conn.:

The authors have produced a well documented warning to the effect that certain high strength aircraft and missile steels must not be allowed to remain unprotected in corrosive atmospheres under high stress for long periods of time. They have rightly pointed out that coexistence of high residual stress and exposure to corrosive media must be avoided throughout manufacture as well as throughout the service life of the product. The data the authors have presented concerning the effect coatings had on the life of stress-corrosion specimens are a valuable contribution to what is known about the protection of ferritic steels from atmospheric corrosion. In these ways the authors' work is a guide to the effective use of high strength steels in aircraft and missile applications. The authors' paper in scope and results is in many respects similar to the work of Noble and Sharp.[1]

The authors took the precaution to say that correlation between specimen tests and service performance has not been established and that the results should not be regarded as a direct indication of expected service performance. In considering whether or not correlation exists between the conditions of these tests and the conditions of fabrication and service, one must carefully distinguish between conditions that have been allowed to exist and those which are inevitable. Because of conditions that have been allowed to exist, high strength steels have received black marks, and despair concerning their use is prevalent in some segments of the missle industry. Now, does the present article make defeatists of the pessimists, or does it rather point the way to successful use of high strength steels?

The discusser's experience with rocket motor cases leads to the conclusion that observing the precautions set forth in the present paper results in successful use of high strength steels. To illustrate—during fabrication when high residual stresses are inevitable, avoid exposure to corro-

sive media; in service where corrosive atmospheres exist, ensure that residual stress levels are low. Always test adequately to ensure that the service time *under applied loads* is less than the minimum expected loaded part life. Applied to rocket motor cases, these are the precautions the authors are pleading for in general.

The authors state that the yield and tensile strengths of the steel in the unstressed condition were not affected by corrosion during exposure periods up to six months. This accords with the discussers' experience with high strength hot work die steel rocket motor cases which performed excellently in bursts test after nine months of handling and storage without benefit of unusual corrosion prevention measures.

While the discussers agree as above concerning the precautions that must be taken, they cannot agree with the implication by the authors that the failure mechanism is an "either-or" proposition. The Introduction to the paper notes that hydrogen embrittlement has been implicated as a cause of failure in missile casings tested with water as the pressurizing medium. The hydrogen embrittlement mechanism has been questioned both implicitly in the paper under discussion and in a private communication[2] from the senior author. The authors report that 12 MoV stainless steel, when stressed and exposed to an aerated solution of 3 percent sodium chloride, fails by corrosion along an active path through the steel. This seems to be true whether the specimen has no current applied to it or if it is anodically polarized or cathodically polarized to a limited degree. That the situation is actually so is amply supported by Figure 13, which shows a micrograph of cracked specimens. Examination of the micrograph seems to indicate that the phenomenon of failure is intergranular in nature, apparently along the prior austenite grain boundaries. While the discussers have no argument with results of these tests on 12 MoV steel immersed in aerated 3 percent sodium chloride solution, (and have seen similar failures in the work reported in reference 1), they wish to point out that missile casings are not hydrotested with a 3 percent aerated solution of sodium chloride. Moreover, the fact that the active corrosion path was intergranular in nature, seems to indicate that the grain boundary area is sensitized in some manner.

Reference 3 is an investigation by the discussers into the failure of high strength rocket motor cases when tested using water as the hydrostatic medium. There is a preponderance of evidence to show that ordinary tap water under these circumstances can cause local hydrogen-induced cracking. The cracks so induced then serve as nuclei for fracture which cause final failure. While space does not here permit a recapitulation of all the evidence indicating that hydrogen-induced cracking may be a factor when normal tap water (as opposed to 3 percent aerated sodium chloride) is used, one important piece of evidence is here presented. It is observed that when hydrogen cracking occurs the resulting cracks are transgranular in nature. In the extensive metallographic investigation undertaken in the course of preparing reference 3 no evidence was found of intergranular cracking. Figure 15 shows typical cracks resulting from hydrotesting with water. As is the case with hydrogen-induced cracking, these cracks originate in a transgranular fashion at the point of maximum triaxiality of stress. This point lies beneath the surface of a corrosion pit. From here the cracks progressed away from the pit and toward the pit surface. The cracks shown in Figure 15 are some which did not initiate failure. Thus their growth may be considered to be representative entirely of the corrosion and hydrogen cracking mechanism with little or no mechanical effect. Incidentally, the test water in the case under consideration contained no appreciable mineral content, phosphides, sulfides or acids which would increase its electrolytic activity. As is the usual case in such phenomena, the charging process was found to be highly sensitive to the area of the casing exposed to water. This is the same as saying it was highly sensitive to specimen size.

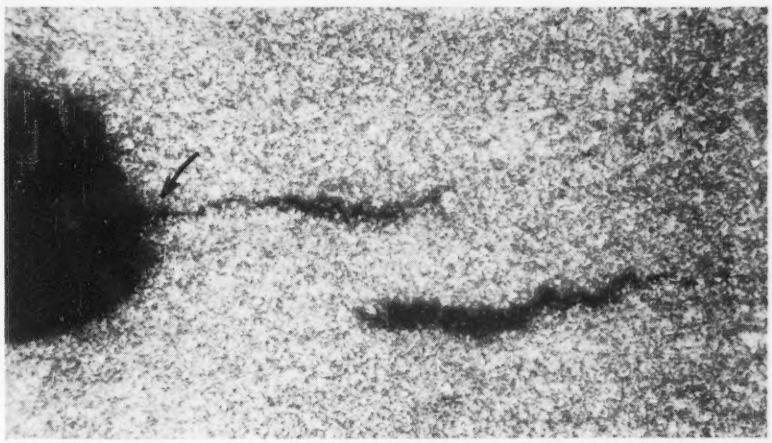


Figure 15

The authors state that positive confirmation of the intergranular nature of the cracks produced by their procedures was made difficult by poor definition of the grain boundaries in their photomicrographs. The discussers suggest that a higher temperature temper of the cracked specimen would produce carbide precipitation in the grain boundaries, rendering them readily visible.

Finally, the discussers would like to point out that the wavy markings at the ends of the stress corrosion cracks in progress in Figure 8 of the author's paper may very well be due to mechanical effects. These markings have the appearance of areas of local yielding at the ends of stress concentrations.

References

1. H. J. Noble and W. H. Sharp. Steels and Protective Treatments for Use up to 1000 F. *Trans. SAE*, 64, 59-75 (1956).
2. E. H. Phelps. Private Communication.
3. M. E. Shank, C. E. Spaeth, V. W. Cooke and J. E. Coyne. Solid Fuel Rocket Chambers for Operation at 240,000 psi and Above. Am. Soc. for Metals, *Metals Progress*, (1959) Nov.-Dec.

Reply by E. H. Phelps and A. W. Loginow:

The authors are indebted to the discussers for their comments on the utilization of very-high-strength steels in the missile industry. It is the authors' intention that the paper will help to point the way to successful use of very-high-strength steels in missile applications.

The authors recognize that missile casings are not hydrotested with an aerated 3 percent sodium chloride solution and also recognize that results on 12 MoV stainless should not be used to interpret the behavior of a hot-work die steel. However, on the basis of the results in the paper, the authors believe that corrosion along an active path is an alternative mechanism for the initiation of the rocket-motor-case failures (described by the discussers) during hydrostatic testing. It is the opinion of the authors that the two mechanisms, hydrogen embrittlement or corrosion along an active path, cannot be distinguished from one another without direct evidence of the type shown in Figure 6.

In the polarization experiments conducted by the authors, a transgranular path was not observed in the range of cathodic-current densities where cracking was attributed to hydrogen embrittlement. As shown in Figure 13, cracking with cathodic polarization was characterized by little or no branching, whereas branching was observed with no applied current and with anodic polarization.

The authors appreciate the discussers' comments concerning the use of a tempering treatment to delineate grain boundaries in cracked specimens, and their comments concerning the cause of the wavy markings at the ends of the stress-corrosion crack in progress, Figure 8.

Any discussion of this article not published above will appear in December, 1960 issue.

Considerations Involved in Choosing Plastic Pipe For Corrosion Control*

By LEONARD F. SANSONE, JR.

Abstract

An evaluation is made of the properties of thermoplastic materials which make them useful for piping applications. The outstanding property of plastic materials, their chemical resistance to a broad range of inorganic and certain organic compounds, is discussed. Test methods and various types of attack observed are discussed to aid in the choice of a suitable material on the basis of chemical resistance.

Physical limitations of thermoplastic materials are pointed out in order that they may be utilized in the area where they are best suited. Examples of several applications are given where plastic pipe has been utilized to solve corrosion problems.

6.6.8

Introduction

ALTHOUGH PLASTIC pipe has many attributes such as low friction factor, ease of installation, and moderate price, the outstanding property of plastic materials is their chemical resistance to a broad range of inorganic and certain organic compounds. Physically, thermoplastic materials are characterized by lower density, lower strength, lower elastic modulus, lower upper temperature limits, and higher thermal expansion than the customarily used metallic piping materials. However, these properties are of such magnitude that by careful appraisal of the physical properties and an evaluation of the environment to which the pipe will be exposed, the excellent chemical resistance of thermoplastics may be utilized to advantage. Among the more important applications of plastic pipe today are conveying potable water, handling salt water and sour crude oil in the oil fields, liquors in the paper industry, and acid pickling solutions in the metal fabricating industry. The materials utilized in these applications and accounting for over 95 percent of total thermoplastic pipe sales are ABS (acrylonitrile-butadiene-styrene) Types I and II, CAB (cellulose acetate butyrate), polyethylene, and PVC (polyvinyl chloride) Types I and II.

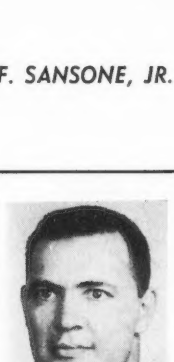
An interesting application of ABS Type I is shown in Figure 1. Shown is the interior of a rotary filter in operation at the Sanitary District of Chicago. The pipe handles ferric chloride and acid solutions as well as abrasive sludges. This installation has a service record of 11 years and still continues to operate satisfactorily.

An installation of PVC Type I which handles hydrochloric acid utilized in a plating process is shown in Figure 2. Absence of chemical attack prevents contamination of the acid and also eliminates dangerous and costly leaks.

In each of the applications described, chemical resistance has played an important part in the selection of plastic pipe. Table 1 has been compiled to compare the chemical resistance of the various materials to four classes of compounds: acids, bases, salts, and organic materials. The first three classes often prove troublesome with metallic piping due to electrolysis and the reactive nature of acids and bases. The organic materials shown in Table 1, when free of corrosive impurities, are ordinarily readily handled by metal pipe.

★Submitted for publication September 14, 1959. A paper presented at a meeting of the North Central Region, National Association of Corrosion Engineers, Cleveland, Ohio, October 20-22, 1959.

About the Author



LEONARD F. SANSONE, JR., planning and development engineer with U. S. Steel's National Tube Division, Pittsburgh, Pa., is engaged in resin evaluation, process development and in preparation of plastics technical service data. He is a member of ASME and the Society of Rheology. He has a BS in engineering from Carnegie Institute of Technology.

Table 1 illustrates that bases and salts are readily handled by thermoplastics, and proper choice of a material can provide acid resistance. Resistance to organic materials is limited, with none of the plastic materials listed being able to handle solvents. It is readily apparent that plastic pipe may be utilized to advantage in environments where electrolysis would take place in metallic systems. Another factor illustrated by Table 1 is that temperature affects chemical resistance markedly as indicated by several instances of changes in rating from "excellent" to "no good" due to increased temperature.

Thermoplastic materials are nonconductors and do not form electrolytic corrosion cells. For this reason they afford excellent service with many electrolytes. Since they are attacked to varying degrees by various reactive compounds and organic solvents, a study of the types of attack observed proves beneficial to the application of thermoplastic materials for corrosion control.

Chemical resistance data is generally obtained by immersing tensile samples in various reagents under controlled temperature conditions, usually for a period of 30 days. The degree of chemical attack is measured by changes in physical properties rather than rate of penetration as with metals. Changes in tensile properties and weight changes are sufficient to indicate the degree of attack. Another method, utilized to determine stress cracking resistance, requires that the sample be stressed during immersion. Certain reagents cause failure under these conditions similar to stress corrosion cracking observed in metals.

When chemical resistance tests are run as described, the effects observed may be listed as follows:

1. Complete failure
   a. Complete solvation
   b. Excessive softening and swelling
   c. Resin breakdown
   d. Stress cracking
2. Partial attack: limited changes in tensile strength and weight

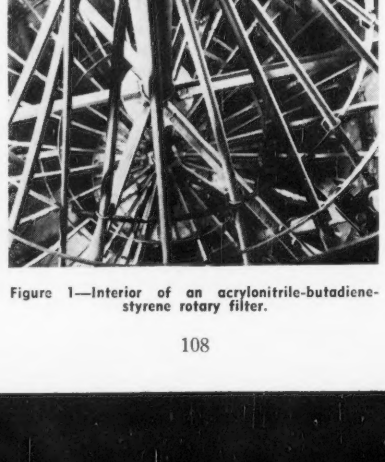


Figure 1—Interior of an acrylonitrile-butadiene-styrene rotary filter.

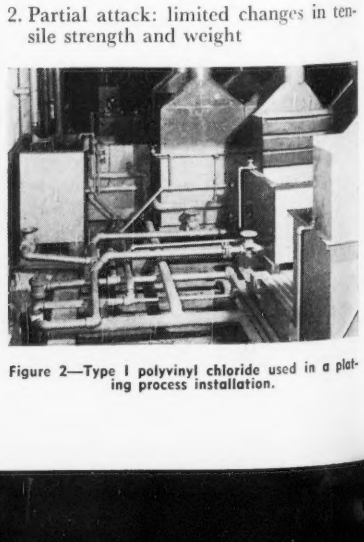


Figure 2—Type I polyvinyl chloride used in a plating process installation.

3. Complete resistance: no changes in physical properties

Complete solvation results when thermoplastic materials are exposed to strong organic solvents, while softening and swelling are observed with weaker solvents. Resin breakdown occurs on exposure to highly reactive compounds, such as concentrated acids, through the alteration of the molecular structure due to chemical reaction. Stress cracking may be observed with reagents having little or no effect on the resin in the unstressed state. Retained stresses from the extrusion and sizing operation or applied stresses are sufficient to cause failure when thermoplastic materials are exposed to stress cracking agents. This is particularly true of ABS II and polyethylene.

Partial attack may be observed with dilute reagents or very weak organic solvents. Attack may result in embrittlement or decreased tensile strength. Depending on the degree of attack, the resistance under these conditions may be rated "no good," "fair," or "good." It is sometimes difficult to determine the proper rating for materials falling in this category, but consideration of the effect of reagents of the same chemical family is often helpful.

When no significant changes in physical properties are noted after immersion, the resistance is rated excellent. Although most of the reagents having an "excellent" rating at room temperature also show excellent resistance at higher temperatures, certain reagents may be rated "no good" at the higher temperatures. For this reason, it is desirable to obtain chemical resistance data at the actual operating temperature.

Utilizing chemical resistance charts, it is quite simple to choose a thermoplastic material having optimum resistance for a particular application. However, piping materials require certain physical property values for suitable application under various conditions. For example, polyethylene exhibits excellent chemical resistance to a wide variety of reagents, but has found little industrial application in the solution of corrosion problems. This is due to its comparatively low temperature resistance, working strength, and elastic modulus. Its low elastic modulus, which would require that it be continuously supported in overhead installations, allows it to be coiled, thus facilitating installation of underground pipelines. It has thus found wide application in potable water lines, principally because of ease of installation and low cost.

Table 2 compares the physical properties of the various thermoplastic pipe materials. The properties listed are those which are especially important in pipe applications. Naturally, high tensile strength and good retention of this property with increased temperature are desirable. Due to the prevalence of creep and stress-rupture phenomena at ambient temperatures, a more important consideration for thermoplastic materials is the working stress.

The working stress is the stress which a thermoplastic material can support for a long period of time without excessive deformation or rupture. Although this property is presently defined in several ways, the Test Methods Committee of the Society of the Plastics Industry is preparing a definition and test method which should be available in the near future. This will be an important achievement due to the importance of the working stress in design and in comparing various materials for a particular application.

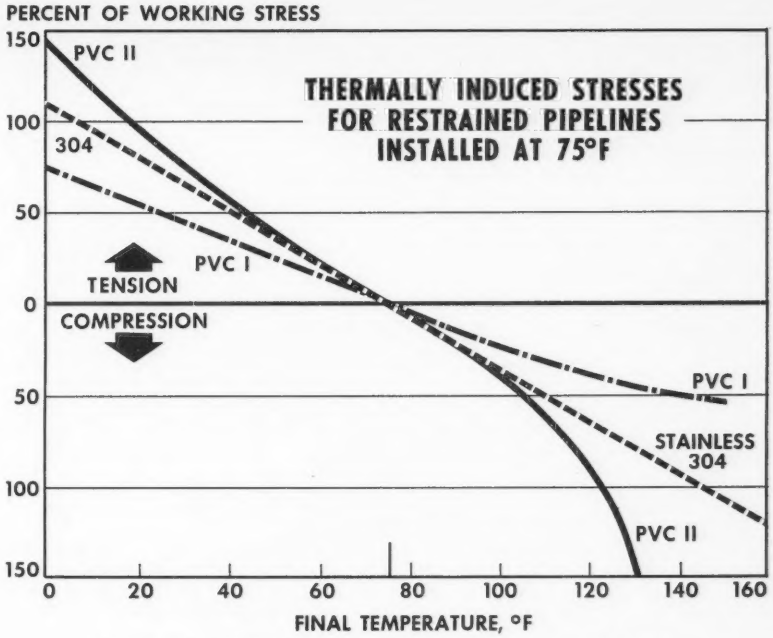


Figure 3—Thermally induced stresses for restrained pipelines installed at 75 F.

Flexural strength and elastic modulus are important considerations in designing piping systems. For overhead lines it is desirable to have these values and the working stress high to avoid excessive support requirements. In the case of flexible polyethylene pipe, it is desirable to have a low elastic modulus so that it may be readily uncoiled and may be effectively joined by clamping.

Impact strength is an important consideration, especially when pipe is to be installed at low temperatures. The notched Izod test has gained acceptance as the criterion for impact strength, since it is more critical than tests employing unnotched samples. Field experience has shown that a notched Izod impact value of about 3 provides very good resistance to breakage. When the impact strength falls below this value, care should be exercised in handling and installation. Field experience has shown that impact strength has not been a problem with any of the materials listed in Table 2, indicating that the levels of impact strength listed are satisfactory.

Many design engineers are surprised and dismayed at the large coefficients of thermal expansion exhibited by thermoplastic materials. They range in value from 4 to 17 times the value for low carbon steel. Due to the limited operating temperature range of thermoplastic piping materials, as indicated in Table 2, thermal deflections noted are similar in magnitude to those encountered in the design of high temperature steam piping. Another factor to be considered is that the elastic moduli of thermoplastic materials vary from approximately 1/1000 to 1/100 of the modulus for steel.

Although a high elastic modulus is generally desirable, a low modulus allows thermoplastic pipe to assume a greal deal of expansion without resulting in excessive stress. An example readily illustrates this principle. Suppose three similar pipelines of PVC I, PVC II and Type 304 stainless steel are installed at 75 F, anchored in place, and brought to a temperature of 120 F. The lines are operating under restrained conditions and will develop compressive stresses due to assuming their own thermal expansion. The compressive stress developed is the product of the expansion coefficient, elastic modulus at the final temperature and the temperature change. Calculations yield the following stress values:

PVC I—377 PSI or 37 percent of working stress

PVC II—440 PSI or 88 percent of working stress

304 Stainless—12,200 PSI or 65 percent of working stress

Stresses for various temperatures, expressed as percent of working stress, are indicated in Figure 3. This diagram indicates that PVC I can more readily assume its own expansion than can Type 304 stainless, although the opposite is true for PVC II.

Generally there are enough changes in direction in a piping system that thermal stresses are relieved by bending and torsion. When excessive deflections are encountered, it is necessary to utilize restraint, slip joints, or expansion loops. Plots similar to Figure 3 may be utilized

TABLE 1—Chemical Resistance of Thermoplastic Pipe Materials

REAGENT	ABS I		ABS II		CAB		Polyethylene		PVC I		PVC II	
	75 F	160 F	75 F	160 F	75 F	150 F	75 F	125 F	75 F	150 F	75 F	130 F
Acids												
10% Nitric	F	NG	F	NG	F	NG	E	E	E	E	E	NG
70% Nitric	NG	NG	NG	NG	NG	NG	G	F	E	E	NG	NG
10% Sulfuric	E	E	E	E	NG	NG	E	E	E	E	E	E
70% Sulfuric	G	NG	G	NG	NG	NG	E	F	E	E	E	E
Bases												
Ammonium Hydroxide	E	F	E	F	F	NG	E	E	E	E	E	E
Calcium Hydroxide	E	F	E	F	G	....	E	E	E	E	E	E
Sodium Hydroxide	E	F	E	F	F	NG	E	E	E	E	E	E
Salts												
Ammonium Chloride	E	E	E	E	G	....	E	E	E	E	E	E
Ferric Chloride	E	E	E	E	G	....	E	E	E	E	E	E
Ammonium Nitrate	E	E	E	E	....	....	E	E	E	E	E	E
Sodium Chloride	E	E	E	E	E	E	E	E	E	E	E	E
Organic Materials												
Acetone	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Benzene	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Ethyl Alcohol	E	NG	E	NG	NG	NG	E	NG	E	G	E	F
Formaldehyde	E	E	E	E	NG	NG	E	E	E	E	E	E

E — Excellent.
G — Good.
F — Fair.
NG — No Good.

TABLE 2—Typical Physical Properties of Thermoplastic Pipe Materials

PROPERTY		ABS I	ABS II	CAB	POLYETHYLENE Type I	POLYETHYLENE Type II	POLYETHYLENE Type III	PVC I	PVC II
Specific Gravity		1.06	1.08	1.20	.910—.925	.926—.940	.941—.965	1.38	1.35
Tensile Strength, psi at									
	32 F	.....	.....	.....	.....	.....	.....	9,500	7,800
	78 F	5,500	8,000	5,500	1,400	2,000	3,500	7,000	6,000
	140 F	2,900	6,000	3,400	700	900	2,200	4,700	3,600
	180 F	1,240	4,550	2,100	.....	.....	1,600	2,900	2,000
Working Stress, psi at	75 F	1,200	1400—2000	850	385	510	600	1,400	1,200
Flexural Strength, psi at	75 F	8,000	12,000	6,200	.....	.....	.....	14,500	12,000
Elastic Modulus, psi at	75 F	240,000	350,000	135,000	35,000	55,000	110,000	450,000	350,000
Izod Impact Strength, ft.—lb./in. notch at	—40 F	.6	.3 to .5	.8	....	....	....	.29	.9
	32 F	1.8	2 to 2.5	....	....	....	....	.44	3.8
	78 F	5 to 9	3 to 4	2.1	>16	4 to 5	6 to 8	.88	10.0
Coefficient of Thermal Expansion, per Degree F x 10^5		5.6	3.8	7.3	11.0	8.0	6.0	2.89	5.56
Maximum Operating Temperature, Degree F		170	180	140	120	120	140	150	130

to determine when restraint is feasible realizing that the thermal stress indicated must be added vectorially to other stresses acting on the pipeline. In using restraint to control thermal expansion, the compressive stress must be kept below the critical value to cause column buckling. If Euler's formula for hinged ends is utilized and guides restricting lateral movement are spaced on this basis, the results will be quite conservative.

Whenever possible, it is good design practice to utilize solvent-cemented joints rather than threaded joints, especially when large thermal fluctuations are encountered. Solvent-cemented joints provide 100 percent of the pipe strength and are readily made up. Threaded joints require about a 50 percent derating factor due to the notch effect and require the use of Schedule 80 or heavier pipe. Threaded joints are especially poor under bending stresses and unless proper allowances are made for thermal expansion, leaking joints may result.

The greatest limitation of thermoplastic materials is their limited resistance to temperature. The highest operating temperature shown in Table 2 is 180 F, but the working stress and other physical properties are drastically reduced at this temperature. Because of the marked temperature dependence of physical properties, it is advisable to observe closely temperature recommendations supplied by pipe producers.

There are several new materials which will extend the upper temperature limit, perhaps to 250 F. Among these are acetal, chlorinated polyether and polycarbonate. These materials are undergoing evaluation to determine the proper area for utilization as pipe.

From the description of the chemical and physical properties, it is readily seen that thermoplastic pipe is best suited for applications requiring excellent chemical resistance but only moderate strength and temperature resistance. There are a surprisingly large number of applications where these conditions prevail. When proper design concepts are utilized, it is often found that thermoplastic pipe is the most suitable as well as the most economical pipe that can be specified. As temperature limits and strength levels are raised with the introduction of new resins, the field of application for thermoplastic pipe will be broadened. It will be even more important then for corrosion and design engineers to be aware of the advantages and limitations of thermoplastic pipe.

DISCUSSION

Question by Norris J. Landis, Midland Bldg., Cleveland, Ohio:

Have you any knowledge of PVC (either type) being involved in stress corrosion cracking? If so what was the exposure associated with it?

Reply By Leonard F. Sansome, Jr.:

No evidence of stress cracking has ever been seen with either Type I or Type II PVC in testing or field experience. PVC has been tested with many surface active agents known to cause stress cracking in other plastic materials.

Any discussion of this article not published above will appear in December, 1960 issue.

Part 3—Distillation Residue Studies

Coal Tar Creosote Studies*

By T. R. SWEENEY, T. R. PRICE and S. M. MILLER

Abstract

Tests were made to determine the proportion of residue necessary to enable coal tar creosote to impart its maximum protection to wood. This was done by exposing a series of wooden panels impregnated with creosotes containing varying percentages of residue to marine borer attack and determining their relative degree of resistance. Preleached and unleached series of treated panels were used in the experiments and, for additional information, leaching rates were determined for the various compound creosotes.

It was found that all distillation fractions studied gave wood panels good resistance to marine borer attack. Resistance to *Teredinidae* attack was much greater than to *Limnoria attack*. Fractions of creosote boiling below 160 C/15 mm were relatively ineffective in preventing *Teredinidae* attack. Creosotes having residue contents between 15 and 50 percent appeared to be similar in effectiveness. The rate of loss of creosote from impregnated wood panels leached with flowing water at 80 C was roughly inversely proportional to the residue content of the creosote. 6.6.11

Introduction

RESEARCH work on coal tar creosote has been carried on at the U. S. Naval Research Laboratory for the past several years in an effort to correlate the chemical composition of creosote with its ability to protect wood against marine borer attack. Insofar as the creosote fractions obtained by distillation are concerned, earlier work[1-5] has indicated that all of the fractions confer upon wood a certain resistance to attack and that the efficacy of the fractions increases with increasing boiling point up to 210 C/15 mm, at which point distillation was discontinued. The material boiling above this point, the so-called residue, enhances the protective ability of the latter fractions by decreasing the rate at which they are leached from the wood.[5] In order to check these results using another approach, four distillation fractions were combined respectively with the residue in the proportion 65 percent fraction to 35 percent residue and the resulting solutions tested for their ability to impart to wood a resistance to marine borer attack. For comparison, a coal tar-creosote solution (30:70) and a "synthetic" creosote-residue solution were included in the investigation.

In addition it was of interest from both the research and practical standpoint to determine the proportion of residue necessary to enable creosote to impart its maximum protection to wood. This was done by exposing series of wooden panels impregnated with creosotes containing varying percentages of residue to marine borer attack and determining their relative degree of resistance. Preleached and unleached series of treated panels were used in the experiments and, for additional information, leaching rates were determined for the various compounded creosotes.

Experimental Procedure

Creosote Distillation

The creosote from which the residue-fraction and residue-creosote solutions were prepared was taken from a stock of AWPA Grade 1 creosote reserved for present and future Navy research. In order to obtain the residue, the creosote was distilled through a saddle-packed, jacketed, heated column, 40 cm long and 2 cm inside diameter, equipped with a heated total reflux head and fraction collector. The distillation was carried out at atmospheric pressure up to 235 C at which point the pressure was reduced to 15 mm and the distillation continued until the temperature reached 210 C. The distillation results are summarized in Table 1. The "residue" of Table 1 is comparable to the residue obtained in the AWPA distillation Standard A1-58[6] and 5-ball distillation.[7]

Preparation of Test Solutions

Residue-fraction solutions were prepared by combining 65 parts of fraction with 35 parts of residue (by weight) and mixing hot until homogeneous. Thirty-five percent residue was chosen for these solutions because this corresponds to the percentage of residue in whole creosote.

The composition of "synthetic" creosote was derived from an analysis of the dozen compounds comprising approximately 50 percent of creosote as reported by Stasse.[8] He reported a naphthalene concentration of 24 percent; methyl naphthalene 3 percent; acenapthalene 3 percent; diphenyl oxide 1 percent; fluorene 3 percent; 9,10-dihydroanthracene 0.3 percent; phenanthrene 9 percent; anthracene 1.7 percent; carbazole 2 percent; fluoranthene 2 percent; pyrene 2 percent. For the purposes of this investigation the concentration of naphthalene was held at 24 percent and the other compounds with the exception of 9,10-dihydroanthracene were mixed in the same ratio as reported to make 100 percent. The compounds were mixed and heated until a homogeneous solution resulted. The weights of constituents to make 1000 g of synthetic creosote were as follows:

Naphthalene	240.0 g
1-methyl naphthalene	42.7 g
2-methyl naphthalene	42.7 g
Diphenylene oxide	28.4 g
Acenaphthene	85.4 g
Fluorene	85.4 g
Phenanthrene	256.0 g
Anthracene	48.4 g
Carbazole	57.0 g
Fluoranthene	57.0 g
Pyrene	57.0 g

The purity and grade of these chemicals was the highest that could be obtained commercially.

Residue-creosote solutions were prepared containing the following percentages of residue: 0, 15, 35 (whole creosote), 50, 75, and 100.

*Submitted for publication August 4, 1959.

T. R. SWEENEY is a research chemist with the U. S. Naval Research Laboratory, Washington, D. C., where he is concerned with the chemistry of wood preservation, especially in marine environments. He received a PhD in organic chemistry from the University of Maryland. He was formerly a research chemist on the staff of the University of Maryland and with the National Institute of Health. A member of ACS and NACE, he is chairman of NACE Technical Unit Committee T-9B on Preservations and Their Appraisal.

T. R. PRICE is a research chemist with the U. S. Naval Research Laboratory, Washington, D. C., where he is engaged in research on wood preservation for marine use. Formerly he was Scientist-in-Charge of the U. S. Naval Research Laboratory Tropical Exposure Site in the Panama Canal Zone. He has a BS from Albright College.

SIGMUND MILLER is assistant professor of oceanography and leader of the Deterioration Prevention Section of The Marine Laboratory, University of Miami, and is also research manager of Miami Marine Research and Test Station. He is engaged in research and development work on marine wood preservatives, and on antifouling and anticorrosive coatings. He has a MS from the University of Miami.

Preparation and Exposure Panels

Clear, edge grain, sapwood, southern pine panels, 5 x 1½ x ⅛ inch, were dried to constant weight (to the nearest 0.1 g) at 105 C before impregnation. Only sapwood, as determined by the benzidine test,[6] was used. Panel weight tolerance was established at 8.25 ± 0.75 g.

Panels were impregnated by submerg-

ing them in the various solutions at 90 C to 170 C (the high residue solutions and those containing the higher boiling fractions required the higher impregnation temperatures) in a pressure vessel and applying nitrogen pressure. After impregnation, the panels were allowed to bleed in a desiccator to constant weight and the pickup in pounds per cubic foot (pcf) calculated from the gain in weight.

For each solution two sets of panels were prepared, each set containing 30 panels. Impregnations were spread as evenly as practicable over the range of 5 to 16 pcf by varying the immersion time and pressure. Before exposure, one of the two panel sets for each solution was subjected to an accelerated leaching in flowing fresh water at 80 C as described elsewhere.[9] This accelerated leaching prior to exposure is an attempt to assess the long-term protective ability and permanence of the preservative. It has been shown[9] that the differential leaching of creosote constituents from impregnated wood by this procedure follows very closely the differential leaching which occurs in flowing sea water at ordinary temperature.

Leached and unleached panels were exposed simultaneously. However, because of the higher rate of attack, the leached panels had to be withdrawn sooner than the unleached panels. Marine borer damage to each exposed panel was rated on a numerical scale from 0 (no attack) to 5 (maximum attack). *Limnoria* and *Teredinidae* damage were rated separately by measuring the area of attack on the faces of the panel and by counting the respective number of burrows.[9]

TABLE 1—*Summary of Creosote Distillation*
(Average of Three Distillations)

Fraction	BOILING RANGE, DEGREES C		Percent Yield
	Actual	Approximate at 760 mm Hg*	
1	$<200_{760}$	<200	2.8
2	200_{760} to 235_{760}	200 to 235	21.8
3	235_{760} to 130_{15}	235 to 255	2.5
4	130_{15} to 160_{15}	255 to 295	9.5
5	160_{15} to 190_{15}	295 to 330	15.4
6	190_{15} to 210_{15}	330 to 355	12.4
Residue	210_{15}	355	34.4

* Taken from nomograph based on "k" Tables of Selected Properties of Hydrocarbons, American Petroleum Institute Research Project 44.

Leaching Rate Determinations

The rate of loss of creosote-residue solutions from wood panels was determined by leaching the treated panels in a bath of flowing fresh water maintained at 80 C; the procedure is similar to that used in preparing the panels for exposure. About 20 panels were used for each solution and all panels were impregnated to about 15 pcf. Four panels with each solution were removed at intervals for each determination. The panels were dried first in air and then in a desiccator over phosphorous pentoxide to constant weight. This procedure is not as accurate as extracting the panels with a solvent to determine the residual creosote but is much more easily accomplished and was deemed accurate enough for the purpose.

Results and Discussion

For presentation, exposure data have been divided into three impregnation ranges: low (5 to 8.3 pcf), intermediate (8.4 to 11.7 pcf), and high (11.8 to 15 pcf) and the average attack for each range calculated. About 10 panels are included in each range. The performance of the creosote distillation fractions when compared as fraction-residue solutions is summarized in Table 2. *Teredinidae* and *Limnoria* damage are noted separately for both leached and unleached panels.

In order to interpret the data presented in Tables 2 and 3 it was necessary to use a statistical method known as the

TABLE 2—Performance of Creosote Distillation Fractions When Compared as Solutions Containing 65 Percent Fraction and 35 Percent Distillation Residue

Solution	AVERAGE ATTACK											
	NOT LEACHED[1]						LEACHED[2]					
	TEREDINIDAE			LIMNORIA			TEREDINIDAE			LIMNORIA		
	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf
Whole Creosote Alone	0.1	0.1	0	1.9	1.3	1.3	0.6	0.1	0	2.5	2.1	1.9
Paraffin-Residue	0.3	0.1	0.2	2.8	2.4	2.0	2.1	1.6	0.6	3.0	2.2	1.7
Fraction-2-Residue	0.2	0.1	0	2.9	2.0	1.6	2.2	1.5	0.4	4.2	3.9	3.5
Fraction-3-4-Residue	0.1	0	0	1.9	1.7	1.0	1.3	0.3	0.2	2.6	1.7	1.3
Fraction-5-Residue	0.1	0.1	0	2.3	1.9	0.9	0.6	0.2	0.3	2.4	1.6	1.9
Fraction-6-Residue	0	0.2	0	2.4	1.6	1.2	1.9	0.2	0.1	2.0	2.0	1.7
Paraffin Alone*	...	...	...	...	...	...	...	...	...	...	...	...

[1] Exposed at Miami, Fla. for 15 months.
[2] Exposed at Miami, Fla. for 7 months.
* Most Panel Destroyed.

TABLE 3—Performance of Creosotes Containing Various Amounts of Residue

Solution	AVERAGE ATTACK											
	NOT LEACHED[1]						LEACHED[2]					
	TEREDINIDAE			LIMNORIA			TEREDINIDAE			LIMNORIA		
	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf	5 to 8.3 pcf	8.4 to 11.7 pcf	11.8 to 15 pcf
Whole Creosote Alone (35 Percent Residue)	0.2	0	0	2.7	2.2	2.3	0.8	0	0.2	4.3	3.8	3.7
Creosote, No Residue	0.8	0.1	0.3	3.1	3.5	3.4	2.3	1.7	1.6	5.0	5.0	5.0
Creosote, 15 Percent Residue	0.3	0	0	2.7	1.4	2.5	1.8	0.5	0.1	4.8	4.6	3.7
Creosote, 50 Percent Residue	0.2	0	0	3.2	2.4	1.9	1.0	0.1	0.1	4.4	3.8	3.0
Creosote, 75 Percent Residue	0.1	0.1	0	3.7	3.5	2.0	1.5	0.1	0.2	4.8	4.3	3.7
Creosote Residue	1.1	0.1	0.1	3.3	2.5	2.4	1.2	0.3	0.2	4.2	4.0	3.2
"Synthetic" Creosote, 35 Percent Residue	0.5	0	0	3.1	2.5	2.1	1.2	0.1	0.4	4.7	4.4	3.5
Coal-Tar Creosote (30-70)	0.6	0.1	0	3.5	2.6	2.8	1.0	1.4	0.2	4.9	4.7	3.2

[1] The unleached panels were exposed for 11 months at Miami, Fla.
[2] The leached panels were exposed for 10 months at Miami, Fla.

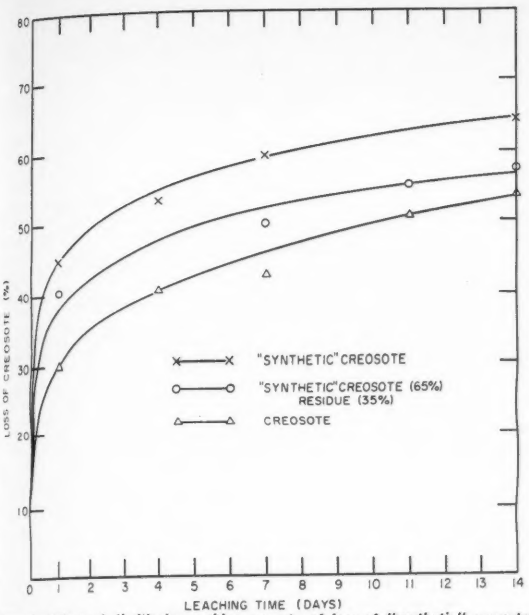


Figure 1—Effect of distillation residue on rate of loss of "synthetic" creosote from treated panels when leached in flowing water at 80 C.

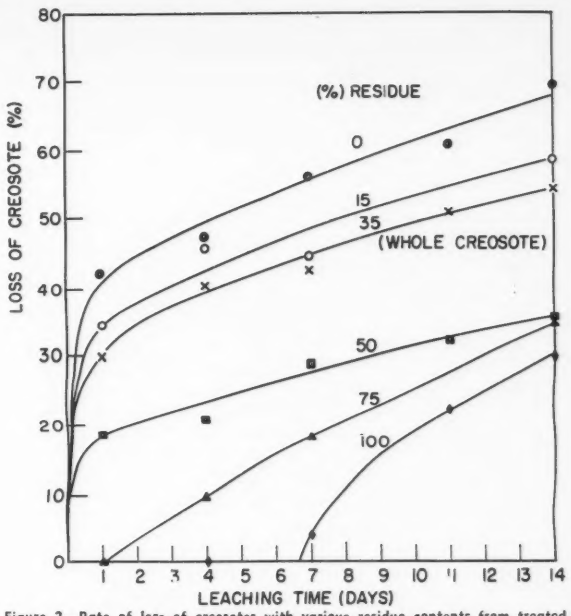


Figure 2—Rate of loss of creosotes with various residue contents from treated panels when leached in flowing water at 80 C.

Wilcoxen Rank Test[10] which can be used to show the probability that differences in sets of data are due to chance fluctuations alone. In the ensuing discussion the term significant is used to mean that there is less than 1 chance in 20 that the differences are due to chance and are not due to real differences in effectiveness.

The data of Table 2 corroborate the now generally accepted fact that an adequate retention of creosote will make wood resistant to *Teredinidae* attack but is much less efficient in preventing *Limnoria* attack.[11,12] All fractions including the distillation residue afforded protection against *Teredinidae* attack but *Limnoria* attack was considerably higher.

Analysis of the data of Table 2 revealed no significant difference in the performance of any of the fraction-residue solutions or of the whole creosote when exposed without leaching. *Teredinidae* attack on the leached panels, on the other hand, show significant differences in performance especially at the low impregnation level. At this level there was no significant difference in the effectiveness of whole creosote, Fraction 5-residue and Fraction 6-residue. However, Fraction 3-4 residue, Fraction 2-residue and paraffin-residue were significantly inferior to whole creosote. At the medium impregnation level Fraction 2-residue and paraffin-residue were again significantly inferior to whole creosote but there was no significant difference in the performance of the other solutions. At the high impregnation level no significant differences could be demonstrated between any of the solutions.

In considering the *Limnoria* attack on the leached panels of Table 2 only the Fraction 2-residue solution was significantly inferior to whole creosote and that only at the low impregnation level. The presence of the distillation residue in these solutions complicated the task of determining the relative effectiveness of the distillation fractions since the residue obviously made a substantial contribution to the effectiveness of creosote as can be seen in Table 3. Differences in the effectiveness of the distillation fractions in such a solution could be determined only at the lower impregnation levels since the larger quantity of residue present at the high level provided a considerable degree of protection which compensated for any deficiencies of the fraction incorporated with it. The presence of the residue probably tended to hold the fractions in the wood for a longer time than would have been the case if the wood had been treated with fraction alone. However, the data support the conclusion that distillation fractions 2, 3 and 4 were not as effective as the higher boiling fractions in preventing marine borer attack.

Exposure data on the creosote-residue solutions together with synthetic creosote residue solution and 30-70 coal tar-creosote solution are presented in Table 3. These data further corroborate the disparity in the resistance of creosoted wood to attack by *Teredinidae* and *Limnoria*. *Teredinidae* attack was appreciable only on the leached panels containing no residue and in the panels in the low impregnation range but *Limnoria* attack was heavy even on the unleached panels at the high impregnation level.

Among the panels not leached prior to exposure no significant differences in performance could be demonstrated. The creosote residue at the low impregnation level was attacked by *Teredinidae* but this was probably due to poor penetration by the viscous material. Among the panels exposed after leaching, the creosote with no residue was significantly worse than whole creosote in preventing *Teredinidae* attack although the other creosote-residue solutions and the residue itself did not differ significantly from whole creosote. Since residue contents of over 50 percent produce a creosote which is very viscous and which penetrates wood rather poorly it appears that, other things being equal, creosotes with residue contents lying between 15 percent and 50 percent will give comparable performances. In other words, within the limits of AWPA Standard P1-54 (15 percent to 40 percent residue) the residue content is not critical. This has been shown to be true in the cooperative creosote program of Richards[13] where low, medium and high residue creosotes all gave creditable performances.

In earlier, unreported work, it was found that a "synthetic" creosote, prepared from eleven of the major constituents of creosote, conferred upon wood a resistance to marine borer attack comparable to that conferred by creosote when treated wood panels were exposed in the sea. However, when the treated panels were subjected to a preleaching in hot water before exposure, creosote proved much superior to the synthetic creosote. This suggested that the synthetic creosote was leached from the wood at a higher rate than were the constituent compounds when they were present as part of creosote, and that if the leaching of the synthetic creosote could be retarded it might confer protection comparable to that of creosote. This was, in fact, found to be the case. A solution of 65 percent synthetic creosote and 35 percent distillation residue showed greater resistance to accelerated leaching at 80 C than did synthetic creosote but less than whole creosote (Figure 1). The synthetic creosote-residue solution showed a resistance to *Limnoria* and *Teredinidae* attack that does not differ

significantly from the performance of whole creosote.

The 30-70 coal tar-creosote solution was not significantly different from whole creosote in any respect. While it had a higher average attack at all levels than whole creosote these differences appear to be due to chance fluctuations.

The rate of leaching of the various creosote-residue solutions from treated wooden panels of the size used in the exposure tests and impregnated to a level of about 15 pcf is shown in Figure 2. It can be seen that the rate of leaching is a function of the residue content of the solution. It has been shown previously[8] that the leaching of whole creosote by flowing hot water follows the pattern of leaching of whole creosote by sea water at ambient temperatures rather closely. It is probable that the creosote-residue solutions would be leached in a similar manner by sea water at ambient temperatures.

Conclusions

1. All of the creosote distillation fractions studied as fraction-residue solutions conferred upon wood panels a resistance to marine borer attack.

2. Resistance to *Teredinidae* attack was much greater than resistance to *Limnoria* attack.

3. The fractions of creosote boiling below 160 C/15 mm are relatively ineffective in preventing *Teredinidae* attack.

4. Creosotes having residue contents between 15 percent and 50 percent appear to be similar in degree of protection afforded.

5. The rate of loss of creosote from impregnated wood panels leached with flowing fresh water at 80 C was roughly inversely proportional to the residue content of the creosote.

References

1. T. R. Sweeney, J. D. Bultman, and A. L. Alexander. U. S. Naval Research Laboratory Report No. 4409 (1954).
2. T. R. Sweeney, T. R. Price, and A. L. Alexander. U. S. Naval Research Laboratory Report No. 4672 (1955).
3. T. R. Sweeney and T. R. Price. U. S. Naval Research Laboratory Report No. 4829 (1956).
4. T. R. Price and T. R. Sweeney. U. S. Naval Research Laboratory Report No. 4851 (1956).
5. T. R. Sweeney, T. R. Price and S. M. Miller. *Corrosion*, **14**, 348t (1958)
6. American Wood Preservers' Association Manual of Recommended Practice.
7. H. L. Stasse. *Proc. Am. Soc. Testing Materials*, **54**, 1258 (1954).
8. H. L. Stasse. *Proc. Am. Wood Preservers' Assoc.*, 50, 13 (1954).
9. T. R. Sweeney, T. R. Price, R. S. Saunders, S. M. Miller and F. G. W. Smith. *Corrosion*, **14**, 295t (1958).
10. G. W. Snedecor. *Statistical Methods*. Fifth Edition, Iowa State College Press (1956), p. 117.
11. C. H. Edmonson. *Occ. Papers of Bernice P. Bishop Museum*, **21**, 87 (1953).
12. J. D. MacLean. *Proc. Am. Wood Preservers' Assoc.*, **27**, 287 (1931).
13. A. P. Richards. *Proc. Am. Wood Preservers' Assoc.*, **52**, 226 (1956).

Any discussion of this article not published above will appear in December, 1960 issue.

Technical Papers on Corrosion Welcomed

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

Insulating Properties of Cement Mortar Coating*

By M. UNZ*

Abstract

Cement mortar is successfully used for the coating of underground pipe lines. It exhibits remarkable insulating properties in withstanding the galvanic forces of underground corrosion circuits. The particular features of the mortar, as a compound electrolytic conductor are considered. A practical method for resistivity measurements is suggested. Corrosive conditions are analyzed. Preventive measures and the criteria for cathodic protection are discussed.

It was found that a portland cement coating owes its protective properties to: (1) Corrosion inhibiting properties, (2) a noble half-cell potential, (3) self-sealing effect, and (4) rise of insulation resistance with the ageing of the line. The mortar coating was found especially suitable for large diameter pipes because of these ageing effects.

The use of bituminous coatings over mortar is discussed briefly. 5.4.2

Introduction

WITH THE development of prestressed concrete pipe, cement mortar became a standard coating material for underground lines. Despite the electromotive forces acting on electrically continuous lines, the cement coating proved in practice to be reliable. It develops an adequate insulation resistance owing to its particular self-sealing properties. The electrochemical half-cell potential of a cement coated structure is 0.5 volt more noble than that of bare or bituminous coated steel. Incipient corrosion currents are limited by the creation of a permanent skin of cement compounds over the steel surface.

The application of this coating requires, however, a thorough knowledge of the process taking place in corrosive environments. The conductance of the mortar is of electrolytic character; its initial insulation resistance is very much lower than that of standard bituminous coatings. A great deal of preventive planning is needed to meet corrosive conditions. Cathodic protection is applicable only to a limited extent.

Comprehensive research has been undertaken by previous workers in connection with corrosion problems on self-contained reinforced concrete structures. The object of this investigation is to analyze the conditions prevalent on electrically continuous cement coated pipe lines, related to current flow and environments.

Cement Mortar

Mortar Properties

The protective value of portland cement mortar depends on its mechanical strength, the electrical insulation resistance and the inhibiting properties.

Adequate strength is required against mechanical damage and tensile stresses. For brush sprayed or semi-plastic tamped mortar mechanical compaction devices are used to obtain a well consolidated and dense coating (Figure 1). Differential cracking is prevented by thorough curing. Every precaution is taken to secure a perfect bond between coating and reinforcement. Hairline cracks of not more than 0.05 mm (0.002 inch) in width are permissible on the hydrostatic test.

The AC insulating resistance is relatively low. For a three-quarter inch thick coating it is, by order of magnitude, only one-tenth of that of a wrapped bituminous coating. It depends on the quantity of soluble salts included in the mortar, the pore volume, the shape and pattern of the grains as well as on the resistivity of the impregnating liquid. Minimum pore volume is obtained by correct mix design, suitable grading of the sand and proper water cement ratio. Absorption factors of the cured mortar range between 4 and 15 percent by weight. Cast concrete can be very impermeable. Pneumatically applied mortar, brush sprayed or semi-plastic tamped mortar can be free of entrapped air pockets and should suffer less from segregation. The latter methods also enable application of a cement slurry priming coat over the steel surface.

The ohmic insulation resistance obtainable with such coatings would be completely insufficient for the protection of underground lines, but for the inhibiting properties of the cement. Owing to the alkaline reaction of the calcium hydroxide contained in the mortar, at a pH of more than 10, a passivation process takes place at the steel surface. This alkaline environment lowers the corrosion efficiency to a few percent.[1] The danger of local corrosive attack is thus reduced in the case of soil moisture penetrating through the interstices of the coating. As a further result of the alkaline conditions, the reinforcement assumes a half-cell potential nobler than on asphalt coated structures.

Cement Skin

Cement mortar has the particular property of removing all rust and loose scale particles from the steel during the curing. The particles are dissolved owing to a superficial corrosion process and form iron salts. These salts are diffused in the mortar and then precipitated.

On prestressed concrete pipe it has been found that after the first few days of curing, cylinder and wires are already free of all rust and loose scale. The reinforcement assumes the gray-blue color of a clean steel surface. At the same time black or dark brown spots of the precipitated compounds appear in the mortar.

Owing to this absorption process an excellent bond is obtained between concrete and reinforcement. The bond is particularly strong when some atmospheric rust has been present on the steel surface. The feature is so characteristic that it can serve as a means of checking

★ Submitted for publication November 2, 1959.

* Water Planning for Israel, Ltd., Tel-Aviv, Israel.

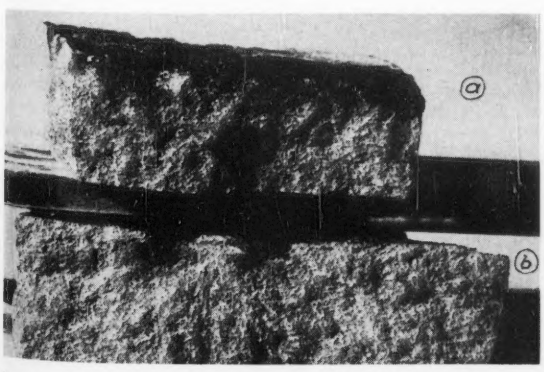


Figure 1—Surface inhomogeneities of brushed cement coating—impregnated with red dye.
(a) At 16 percent absorption, without compaction
(b) At 10 percent absorption with inadequate compaction

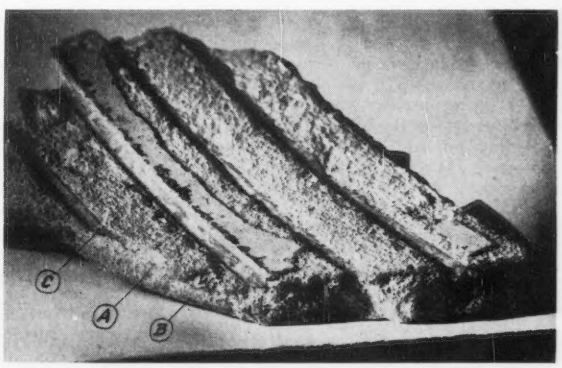


Figure 2—Coating sample chipped off an anodic section of underground line. Note the protective cement skin in wire rills and at cylinder surface.

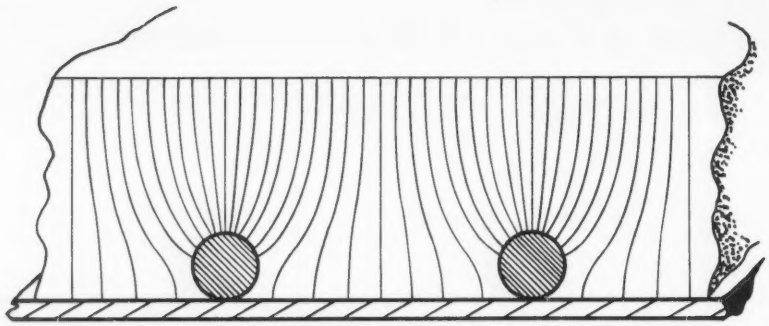


Figure 3—Electrical current field in the coating of SP5 cylinder type prestressed concrete pipe—sketch.

TABLE 1—Chemical Analysis of Coating Samples Taken from Anodic Sections of an Operating Line*

Description	SAMPLE 468			SAMPLE 265		
	A Middle Layer Percent	B Outer Layer Percent	C Normal Cement Skin Percent	D Middle Layer Percent	E Fissured Black Skin Percent	F Rusty Mortar Spots Percent
Insoluble SiO_2**	22.65	28.65	41.66	55.47	9.56	51.29
Soluble SiO_2**	11.09	10.63	7.68	5.29	2.90	5.07
Calcium carbonate, $CaCO_3$	31.90	31.18	15.36	30.11	7.92	1.90
Calcium oxide, CaO***	16.18	15.22	21.45	2.42	0.57	0.54
Other mortar components	17.85	13.43	12.81	6.44	6.48	10.85
Total	99.67	99.11	98.96	99.73	27.43	69.65
Corrosion products:						
Iron-oxydul-oxide (Magnetite), Fe_3O_4	—	—	—	—	17.86	—
Iron-oxide-hydrate (Goethite), $Fe_2O_3.H_2O$	—	—	0.79	—	55.16	31.48
Total	—	—	0.79	—	73.02	31.48
Cement content	56.0	53.7	38.8	26.7	14.7	25.6

* For sample marks see Figures 2 and 4.
** In accordance with ASTM—C 85-54.
*** Calcium oxide in addition to that bound as $CaCO_3$.

visually the mortar composition on chipped off bits of the coating. In the zones of cement deficiency due to poor mix or to segregation, the mortar coating is more porous and lighter in color. No traces of rust absorption are found there. The rust also remains on the reinforcement in places where the steel surface has been greasy and at eventual air pockets of the mortar.

A similar process develops in the anodic sections of a buried or submerged line. An electric current is discharged from the reinforcement through the coating as a result of galvanic ground potentials. This current causes a dissolution of tiny quantities of steel at the interface of the alkaline mortar. The iron oxides produced in the incipient corrosion process react with the mortar components. A dense gray-black layer is formed, (i.e., the "cement skin"), as found by the writer in an earlier work.[2] This layer closely envelops the reinforcement, thus providing an additional barrier for its protection (Figure 2). The density of the oxide skin is so high that a drop of water placed on the surface shows no signs of absorption after 30 minutes. Over the steel tension wires of prestressed concrete pipe the skin is about twice as thick as over the cylinder sheet, due to the congestion of current lines existing there (Figure 3). The density of the oxide layer decreases with the distance from the steel surface, until it becomes that of normal mortar. In regions where segregation has taken place, a thin layer of absorbent, gray-white material is found on the inner surface of the skin, in contact with the reinforcement. This layer has evidently not participated in the formation of oxide compounds. Cases are known where the inner white layer, about 0.5 mm thick, even had a taint of brown rust.

The skin thickness depends primarily on the ampere-hours of current discharged. From one millimeter onwards, however, fissures appear in the skin which provide leakage paths for penetrating moisture. The oxygen thus gaining access to the steel surface reacts with the dissolved ferrous hydroxide, $Fe(OH)_2$. It forms red-brown ferric oxide compounds, similar to plain rust. These ferric compounds are highly absorbent (Figure 4). As their volume is 2.2 times larger than that of the original metal, an internal pressure is created, which eventually cracks open the coating.

The primary importance of the cement skin will be illustrated on examples from an old prestressed concrete line. The pipe was of the non-embedded cylinder type, covered with a brush coating of 1.8 cm nominal thickness. The mortar, from the early stages of production, had an absorption of up to 16 percent. There was also no adequate layer of cement slurry at the steel surface. A section of the line passed through a highly corrosive sandy clay of up to 3600 ppm chloride content and over 2000 ppm of sulfates. Coating samples taken from anodic zones were found to be after 6 years in a satisfactory condition, despite the original weakness of the mortar. They were covered on their inner surface with a 0.2 mm thick layer of dark gray cement skin and the steel surface proved to be in a perfectly preserved state.

A chemical analysis was undertaken on these samples to ascertain the effects of the incipient anodic currents. The results for two extreme cases obtained from K. Taussig are given in Table 1. Referring to test 468-C, the cement content at the steel surface was normal at 38.8 percent, as against a surplus of cement, about 55 percent, in tests 468-A and -B. There were 41.7 percent insoluble silica and 15.4 percent calcium carbonate. The presence of 0.8 percent additional iron oxides indicated the incipient corrosion process which had led to formation of the protective skin. These positive results were attained despite a high content of soluble salts in the mortar. There were 0.27 percent of Cl-ion and 0.59 percent of SO_3, most of which must have been brought-in from the surrounding soil by ion migration.

An entirely different picture was obtained on sample 265 taken from a pipe which had been found damaged in slightly corrosive soil of 400 ohm-cm (measured on water saturated samples). This coating was only 1.3 cm thick. Analysis revealed that due to segregation, the cement content at the wire surface hardly reached 15 percent (Test 265-E). There was also a deficiency of insoluble silica (clean sand), at 9.56 percent, as compared with over 50 percent in the mass of the coating. Consequently excessive discharge currents developed which turned the cement skin into a black, clearly defined oxide crust of 0.4 to 1.5 mm thickness. The crust was uneven and fissured, with red brown rust veins penetrating through it. The particles of the black material were magnetic. They contained as much as 73 percent of iron oxides. The results of the analysis indicate that most of the calcium carbonate, $CaCO_3$, and free calcium oxide, CaO, had been removed from the black layer. The alkalinity of the middle layer (265-D) was reduced to a pH of 6.8 to 8.0.

In samples of rust stained mortar taken from the coating 0.5 cm above the cylinder surface (Test 265-F), an adequate amount of insoluble silica, 51.3 percent, and 25.6 percent cement were found. But these spots, without the cover of a protective skin, were subject to the oxidizing action of penetrating soil moisture. Over 31 percent of iron oxides were found in the rusty patches and not more than 1.9 percent calcium carbonate.

An attempt has been made to compute the mean current density considered to have acted on sample 265. Starting from the volume of the black crust, the equivalent weight of metallic iron was consumed in the internal corrosion process equal to 830 g per m^2. Under the assumption that the black layer was building up steadily at a mean corrosion efficiency of the order of $\eta = 0.20$, about 455 mamp. year/

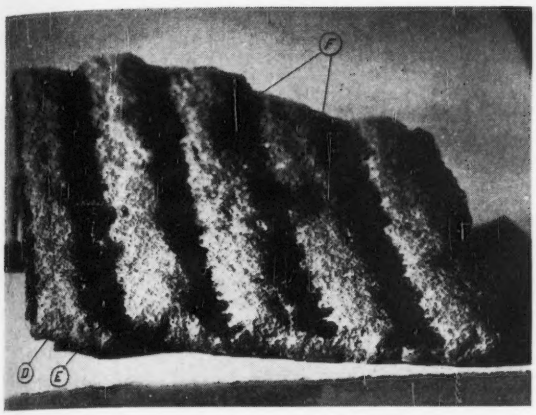


Figure 4—Sample taken from inadequately coated corroded pipe. The black traces consist of impervious black iron oxide compounds from the bottom of the wire rills. They are 0.4 to 1.5 mm thick. The brighter spots indicate red-brown rusty patches.

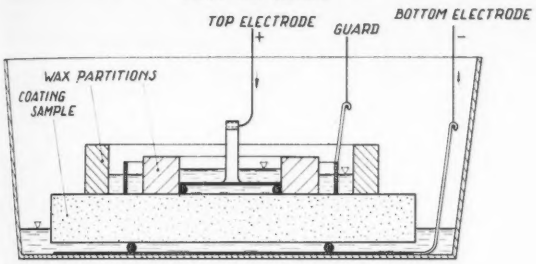


Figure 5—Electrolysis test on coating samples—cross-section.

Figure 6—Electrolysis test on coating samples—assembly.

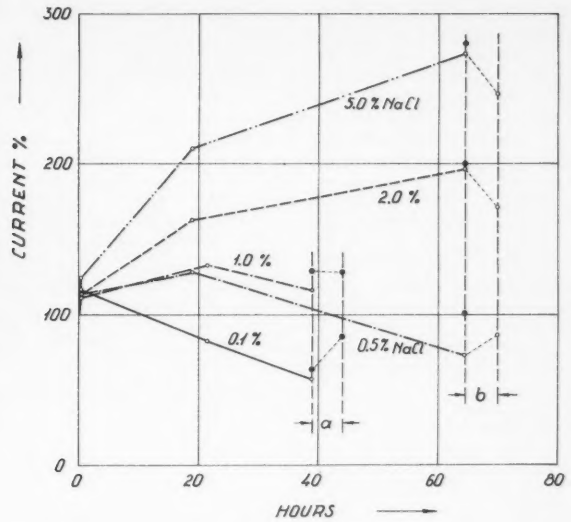


Figure 7—Current intensities in electrolysis test—top electrode anodic. White dot represents electrolyte left undisturbed. Black dot represents situation after stirring the electrolyte.

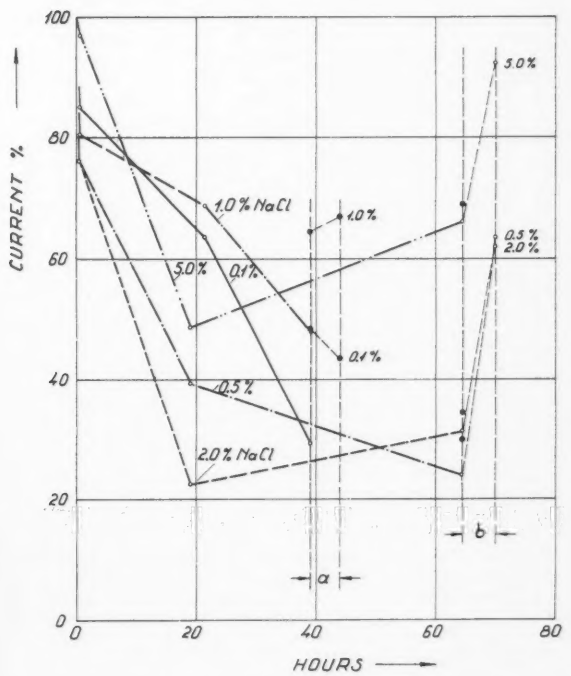


Figure 8—Current intensities in electrolysis test-top electrode cathodic. White dot represents electrolyte left undisturbed. Black dot represents situation after stirring the electrolyte.

m² were required for its formation. This is equivalent to an average current density of

$$j = 76 \text{ mamp/m}^2$$

over a period of 6 years. It should be noted that this estimate holds for the corroded areas of the coating only. Similarly it follows that the dark gray skin of the well preserved sample 468 has an equivalent weight of metallic iron equal to 2.77 g/m². At an assumed mean efficiency of 10 percent the average current density would be

$$j = 0.52 \text{ mamp/m}^2.$$

But the bulk of the current had probably been discharged at very much higher densities, prior to the formation of the protective skin.

The cement skin has much in common with the protective oxide films over certain metals. As in the case of aluminum or stainless steel, newly laid concrete pipe can, or even should be subjected to moderately anodic conditions, until the protective barrier is built up. The cement skin is very much thicker than the metal oxide films and in addition, it is mechanically shielded by the remainder of the coating. It keeps the anodic steel surface on a noble potential, though less noble than that originally achieved. Cases are known where brown rust stains had already penetrated to one third of the coating thickness, but the pipe still re-

mained in good shape, thanks to the self-sealing properties of the cement skin.

Cathode Effects

A different process develops in the cathodic zones of the reinforcement. The steel remains well preserved there in all stages of the electrolysis, but the known cathodic reaction causes an increase of alkalinity. This excessive alkalinity ultimately leads to a decomposition of the cement.

A distinct softening of standard portland cement concrete was already observed in 1913 by Rosa, Burton McCollum and Peters of the National Bureau of Standards.[1] In a comprehensive series of tests on reinforced concrete cylinders they found that the process started at the steel surface with a weakening of the bond and spread outwards up to a radial distance of 0.6 cm. The disintegrated material was darker and could be clearly distinguished from the sound mass of the concrete. Finally, the cement could be shaved off at the reinforcement like soft soap stone. Upon exposure to the air the mushy material became very hard again, though it turned brittle. The rest of the concrete body remained entirely unaffected and retained its normal crushing strength.

A chemical analysis of the electrolysis products indicated a concentration of sodium and potassium at the cathode, as a result of ion migration. Quantities of aluminum and silica were found in the same region, doubtlessly due to the solvent action of sodium and potassium hydroxides on the silica and alumina compounds of the concrete. Portland cement was used for the concrete samples, with 1.25 percent total contents of K_2O and Na_2O. Clean quartz sand and distilled water were used for the mix as well as for the electrolyte. The tests were conducted for several thousand hours at current densities ranging between 2200 and 4500 mamp/m². The voltage gradient at the steel surface was in the order of 4 V/cm. The authors arrived at the conclusion that the cathode effect was caused by a cumulative ampere-hour process, depending on the amount of alkali metals, Na and K, present at the steel surface. The source of these metal ions was either in the concrete proper or, by electrolytic ion sweep, from the surrounding medium. No disintegration was observed on concrete free of alkali metals.

The results of the 1913 investigation were borne out by a series of tests, concluded in 1948 by G. Mole of the British Electrical and Allied Industries Research Association.[3] The following limit values of the current density j were established for concrete free of sodium and potassium:

No loss of bond to be anticipated at: $j < 200$ mamp/m²;

Disintegration takes place at: $j > 20{,}000$ mamp/m².

An odd case of increased bond strength was observed in the lower range of current densities. The effect was found to be due to an adherent cathodic deposit of calcium carbonate at the steel surface. The precipitation of this carbonate was apparently caused by a secondary process in connection with increased diffusion of dissolved carbon dioxide through the concrete. Attempts to reproduce the improvement of bond strength by electrolytic means and to utilize it for industrial purposes did not prove economical.

The fact that concrete free of alkali metals successfully withstands cathodic current densities up to 200 mamp/m² is of primary importance. Good portland cement[4] is at present supposed to contain not more than a total of 0.6 percent of the alkalies Na_2O and K_2O. The coating used by this company contains only 0.2 percent alkalies including the aggregates (i.e., less than 1/6 of the alkali contents in the 1913 tests). If it is considered that even on a cathodically protected concrete line the density of the pickup currents seldom exceeds 10 mamp/m², no impairing of the bond strength appears possible in inert soil.

In soils with excessive salt contents, however, a steady flow of metal ions develops towards the cathode. All the Na and K ions required for the cathodic disintegration may thus become available at the steel surface. Even though the current density of 10 mamp/m² is only 1/200 of the densities applied in the Bureau of Standards' destruction tests, an eventual weakening of the bond strength must be taken into consideration. Referring to existing practice, it is found that the following cathodic current densities exist on bituminous coated steel lines:

Maximum potential difference permissible in drainage systems: 2.0 volt;

Equivalent maximum current density in drainage systems: 4.0 mamp/m²;

Current densities used for the rapid descaling of steel: 4000 to 10,000 mamp/m².

This means that on bituminous coated lines the maximum cathodic current density should, roughly, not exceed 1/2000 of the density used in the industry for the rapid descaling of steel. On a watt-hour basis this ratio favorably compares with the figure of 1/200 previously assumed with respect to the 5500 hour tests on mortar coating. A more definite figure for the permissible maximum current density will have to be statistically established by investigation of mortar samples taken from low resistivity sections of operating drainage systems.

Electrical Resistance

Electrolytic Conductance

Dry concrete is practically a perfect insulator, but the smallest amount of humidity gives it a considerable degree of conductivity. In its moisture saturated state concrete exhibits all the properties of an impregnated porous membrane. There is a polarization voltage which is controlled by the conditions at the electrode surface and an ohmic resistance component governed by the ion movement through the pores of the coating.

In impressed current systems the polarization potential is usually determined by applying an intermittent voltage and

TABLE 2—Chemical Analysis of Solutions Used for Electrolysis Tests

Sample No.	NaCl Nominal, Percent	Electrode Polarity	Current Throughput, mah	Initial NaCl, mg/l	RESULTING CONTENT, MG PER LITER						Resulting pH, Approx.
					NaCl	Ca	HCl	NaOH	Na_2CO_3	$NaHCO_3$	
At Top Electrode											
21-T	0.8		—	7600	7310	130	—	—	—	672	9.3
22-T	0.8	—	87	7600	2630	110	—	—	5936	1008	10.5
23-T	0.8	+	277	7600	6020	330	21.9	—	—	—	5.2
24-T	2.8	—	89	28055	19000	190	—	3520	5724	—	11.0
25-T	2.8	+	323	28055	32150	180	160	—	—	—	< 5.0
26-T	7.0	—	54	70138	13850	170	—	5760	4876	—	>11.0
27-T	7.0	+	326	70138	74810	240	146	—	—	—	< 5.0
28-T	7.0		—	70138	.....	60	—	—	954	776	9.2
At Lower Electrode											
21-B	0.8		—	7600	7679	28.6	—	—	1590	2700	9.0
22-B	0.8	+	87	7600	7700	4.7	—	—	273	700	9.4
23-B	0.8	—	277	7600	8084	4.6	—	—	1170	298	9.8
24-B	2.8	+	89	28055	29020	4.1	—	—	707.8	1079	9.6
25-B	2.8	—	323	28055	28700	5.2	—	208	1735	—	10.5
26-B	7.0	+	54	70138	71060	6.7	—	—	248	825	9.0
27-B	7.0	—	326	70138	71400	2.5	—	321	1824	—	10.7
28-B	7.0		—	70138	70910	6.6	—	211	1315	—	9.8

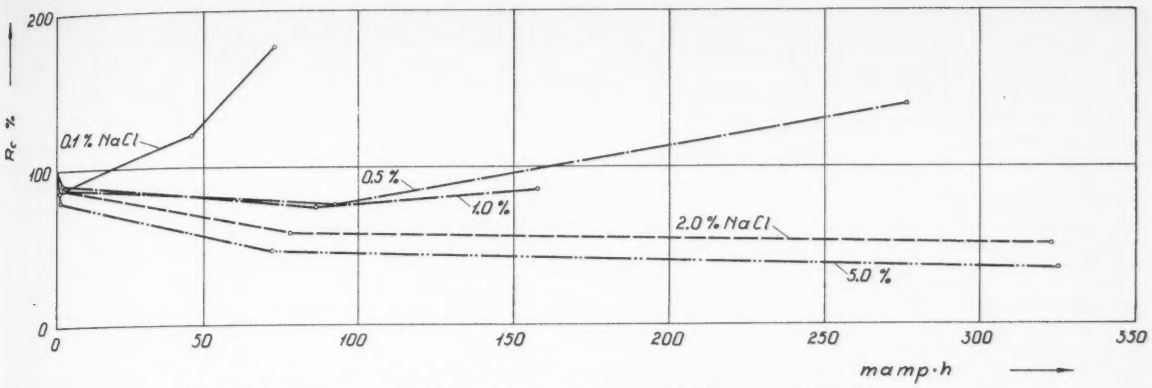


Figure 9—Coating resistance in electrolysis test versus current throughput—top electrode anodic.

taking instantaneous structure to soil readings, φ_p, after a current break. The difference between this potential and the natural basic potential, $\varphi_p - \varphi_b$, gives the polarization voltage. On cement coated lines the degree of polarization depends on the amount of moisture penetrating from the surrounding soil. On prestressed cylinder type pipe, for example, with ¾ inch coating of 9 percent absorption, buried in damp soil, the polarization voltage reached 200 to 300 mV within three days.

The ohmic resistance component is defined as the mean value of the volt/ampere ratio in a commutated DC circuit. In order to determine it under controlled laboratory conditions the following method was developed. A number of coating specimens in the form of 15 cm square plates were cut from the coating upon its application to a dummy pipe cylinder. After curing, the plates were dried and the absorption measured. Thereupon the samples were placed in electrolysis cells filled with sodium chloride solutions of different concentration. They were left immersed for 14 days before switching on the impressed current.

The electrodes consisted of sheet iron plates, kept at 0.35 cm distance from the sample surface. The bottom electrode extended over the whole sample area. The top electrode, 4 cm in diameter, was placed in an enclosure of petroleum wax, cast on to the upper sample surface (Figures 5 and 6). A plastic ring on the periphery secured the spacing of the electrode. It also blocked the free circulation of electrolyte between the upper and the lower portion of the top enclosure. An outer concentric paraffin partition produced a circular channel, which was also filled with electrolyte. This channel served as a guard ring against creepage currents, with a cylindrical electrode for their collection. The material of this electrode had to be the same as that of the main electrodes to eliminate internal potential differences.

As the access of oxygen to the space under the top plate could be controlled at random, the set-up enabled a reproduction of the conditions prevailing in practice. By sealing the top plate on to the sample the performance at the steel surface could be demonstrated, except for the bond strength. For the present resistance measurements, however, it appeared preferable to leave a limited amount of electrolyte under the top plate. Free ion migration was thereby facilitated so as to make the measurements reproducible. The resistance of the thin solution layers between electrodes and coating was negligible at concentrations exceeding 1 percent NaCl. At smaller concentrations it could be readily computed and deducted from the total resistance. Nine volt DC was used for the electrolysis, with either the plus or the minus pole connected to the top electrode. The volt/ampere method was applied for resistance measurements, at 6 volt commutated DC. For the internal potential differences a 100,000 ohm/volt instrument proved satisfactory.

The currents measured at 9 volt were in the order of 0.7 to 6.0 mamp. corresponding with current densities of about 700 to 6000 ma/m². Readings had to be taken instantaneously to avoid the building up of polarization potentials. Existing polarization due to previous current passage was eliminated by taking the average of a number of reversed current readings. The measurements were repeated after a day or two to observe the trend of the performance in its initial stages.

Figure 7 gives the change of the currents during the electrolysis. The top electrode was connected to the plus pole of the power supply (i.e., it was anodic). The brine concentrations were between 0.1 and 5.0 percent NaCl. In view of the unavoidable differences in the original sample resistivity, percentage values are given in the graph with respect to the initial current of each specimen. It has been found that at 0.1 percent brine concentration the current decreases, evidently owing to an increase of resistance caused by the anodic cement skin. At 0.5 and 1.0 percent NaCl this effect develops only after 20 hours. At 2.0 and 5.0 percent the current rises continuously due to the penetration of conductive ions interfering with the self-sealing process.

Stirring the electrolyte abolished existing polarization potentials but did not seriously affect the mean value of the current, as shown by the solid circles in the graph. The currents increased a little due to oxidation of the corrosion products accumulated under the top electrode. This could be observed as the dark green or black sediment turned gray brown during the mixing. An interruption of the current for 98 hours on the 0.1 and 1.0 percent samples, as indicated under (a) in Figure 7, produced an effect supplementary to that of stirring. The oxidation process then probably proceeded under the influence of diffusing oxygen. The cleaning of all surfaces and filling with new brine, as indicated in the graph under (b), slightly reduced the previously attained electrolysis effect, but still left the bulk of the modified resistance unaltered.

For a cathodic top electrode, connected to the minus pole of the supply, all currents first decreased rapidly. Those for 2 and 5 percent NaCl then started increasing (Figure 8). Within a few hours the solution levels over the top electrodes rose up to 4 mm due to gas development underneath. At the higher concentrations, foam accumulated over the top electrode. Stirring the electrolyte at the lower concentrations notably increased the current, evidently due to a filling up of voids which had been occupied by gas. At 5 percent NaCl, where a forced gas flow had already developed, the results of stirring were insignificant. The removal of all loose deposits and refilling with new electrolyte, as indicated in the graph under (b), abolished the electrolysis effect by one half and even more. The squeezed out electrolyte thereby probably returned to the mortar pores, while leftover calcareous precipitation was responsible for the permanent component of the resistance rise.

Inspection of the coating surfaces upon dismantling of the assemblies fully verified the previous statements. On the anodic samples a similar dark green deposit was found under the top electrode, as known from the iron oxide globules under the coating of corroding concrete pipe. The deposit assumed soap stone hardness in dry state. Its upper surface, in contact with air, turned into red-brown rust. Inside it became gray black. The layers were 0.1 to 0.3 mm thick and gradually spread into the solid coating mass underneath. The cleansed coating surface proved to be very dense and fairly impermeable. When a drop of

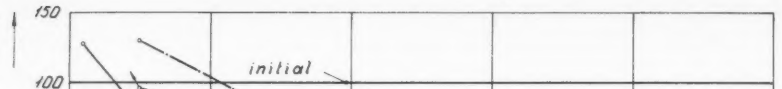


Figure 10—Coating resistance in electrolysis test versus concentration of solution—top electrode anodic.

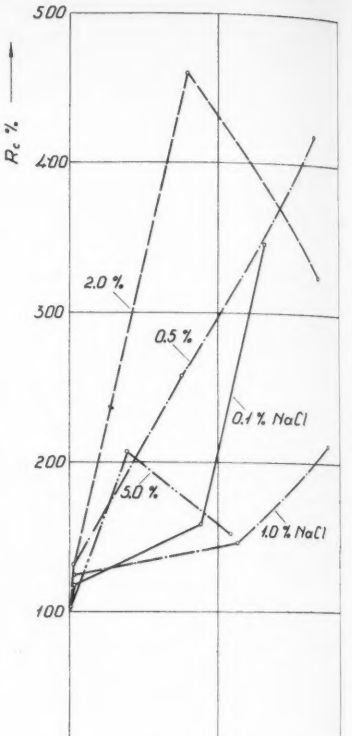


Figure 11—Coating resistance in electrolysis test versus current throughput—top electrode cathodic.

water was placed on it, it took 15 minutes for it to be absorbed, as against 10 seconds required for complete absorption in other points on the sample. This was evidently an initial stage of the cement skin, whereas the soft deposit produced in contact with oxygen diffused in the electrolyte remained hygroscopic.

Under the top plate of the cathodic samples the electrolyte remained perfectly clear. The mortar surface was found covered with an adherent solid calcareous precipitation up to 0.1 mm thick. This deposit was practically impermeable. The mortar underneath was of the same low permeability as the anodic skin. On both the anodic and the cathodic samples a noticeable increase of density was also observed on the lower surface. Calcium hydroxide solution, $Ca(OH)_2$, was probably discharged there or squeezed out by cathodic gas pressure, and precipitated in the form of calcium carbonate, when reacting with the CO_2 dissolved in the electrolyte.

A chemical analysis of the electrolyte applied for a similar series of tests gave the results listed in Table 2. The figures were evaluated by K. Taussig and correlated with the conductivities. The quantity of solution taken on by the mortar was thereby determined and found to be, roughly, in agreement with the absorption factors. All results were related to the solution volume left in the compartments. In order to determine the effects of calcium hydroxide diffusion two dummy samples, without electrodes, were included in the tests. Other secondary effects, due to coating inhomogeneities, capillary action and evaporation inside the test containers had to be neglected. The current throughput on the samples with negative top electrode amounted to about 70 milliampere-hours, whereas it was of the order of 300 milliampere-hours on the samples with positive top electrode.

On the dummy samples 21 and 28 the sodium chloride concentration remained practically unaltered. But notable quantities of sodium hydroxide, NaOH, sodium carbonate, Na_2CO_3, and sodium bicarbonate, $NaHCO_3$, were found in the electrolyte. This was probably caused by the diffusion of calcium hydroxide from the mortar in presence of carbon dioxide from the air. These compounds were mainly alkaline as indicated by the pH values of the solutions. On the electrolyzed samples, at an initial concentration of 2.8 and 7.0 percent, the sodium chloride content strongly declined at the top cathodes, while it rose at the anodes. On sample 24-T, for example, 19,000 mg/l NaCl were obtained, against 32,150 mg/l on 25-T, as compared with an initial content of 28,055 mg/l on both samples. It should be remembered that the large decrement of the cathodic sample 24-T took place at less than one third of the milliampere-hours applied to sample 25-T. The respective sodium chloride concentrations at the lower electrodes 24-B and 25-B remained nearly equal, evidently owing to the very much larger solution quantities. Very small amounts of calcium were found in all the tests, as most of it had been removed by the current or had been precipitated.

The presence of alkaline or acidic compounds in the resulting solution is of particular interest. For 7.0 percent NaCl initial concentration, for example, the cathodic sample 26-T contained 57.6 mg, equivalent with 5760 mg/l sodium hydroxide, NaOH, and 48.8 mg (i.e., 4880 mg/l) sodium carbonate, Na_2CO_3, at a pH of more than 11.0. On the anodic sample 27-T an equivalent of 146 mg/l hydrogen chloride was found at a pH of less than 5.0. These compounds were by ion displacement derived from the NaCl solution and, partly, also from the mortar.

Change of Ohmic Resistance

The quantitative changes of the coating resistance must be considered with respect to the current throughput (Figure 9). Thanks to the cement skin the coating resistance of the anodic samples rose at 0.1 percent NaCl to 180 percent after less than 80 milliampere-hours. At 0.5 percent NaCl it reached 140 percent, after 275 mah. At higher concentrations, however, the resistance decreased owing to the disturbing effect of the chloride ions accumulating in the mortar.

Figure 10 gives the change of resistance after a given current throughput versus electrolyte concentration. With a constant value of 100 percent for R_c in the initial stage, there is a higher resistance at all throughputs up to a concentration of 0.4 percent NaCl. With further increasing concentrations the resistances decline, with those for a larger current throughput assuming lower values. The graph clearly shows the dependence of the resistance and thereby also of the mean resistivity, on the history of a specimen. Previous curing and immersion processes as well as the current flow significantly alter the electrolytic performance.

On the cathodic samples (Figure 11) the resistances increased at the lower concentrations up to 420 percent during the initial hundred mah. At 2.0 and 5.0 percent NaCl they rose at first but started declining within the initial 50 mah. It will be noted that the resistances for the 1.0 and 5.0 percent solutions do not match the other values. The reason for this has been found in the originally very high resistivities of the respective specimens. As the cathodic rise of resistance is produced by internal gas pressure and calcium carbonate precipitation, it greatly depends on the pore configuration. Consequently, the change of the cathodic resistance is significantly affected by the texture of the mortar samples.

When relating the above mah values to current densities at the upper surface of the sample, 50 mah would be obtained for example for an equivalent value of 52,000 mah/m². On a concrete line in corrosive environments, with 1.0 ma/m² natural current density at the cylinder surface, 52,000 hours or 6 years would be required to attain a similar effect. Thereby it should be noted that in the present study the building up of the cement skin was badly impaired by the necessity of keeping the space under the top electrode accessible. In the Bureau of Standards' long range tests on reinforced

concrete samples, a resistance rise of 137 times the original resistance was attained on anode specimens at current densities exceeding 300 ma/m², for 5500 hours.[1] On cathode specimens the respective permanent rise of resistance was 14 times the original value at about 3000 ma/m² for the same time. Fresh water with insignificant salt content was used there for the electrolyte.

The rise of mortar resistivity with the current flow in high or medium resistivity environments is of importance for the protective value of the coating. This positive ageing feature holds for both the anodic and the cathodic sections of a line.

Resistivity Measurements

In view of the complex nature of the mortar performance routine resistivity measurements are of primary importance. The resistivity can be readily determined with the electrolysis cell suggested. When the resistance R_c has been found, the mean volume resistivity of the sample follows from Ohm's law

$$\rho_c = \frac{A}{t} \cdot R_c \text{ (ohm. cm)}.$$

Therein t denotes the thickness of the sample, and A the effective mean cross-sectional area of the current paths. For the computation of A the presence of the shielding channel as well as the current spread in the mass of the sample must be taken into consideration, similar to the method given in ASTM-D257T. The initial resistivity values have been computed in this manner, assuming

$$t = 3.2 \text{ cm},$$

$$A = 17.5 \text{ cm}^2,$$

and listed in Table 3.

The respective coating specimens consisted of 1:2 brush sprayed mortar with a water cement ratio of 0.28. Their inner surface was lined with a half millimeter thick layer of neat cement slurry. Despite approximately equal absorption factors the results cover a wide range of resistivities, due to inhomogeneities of the mortar. In addition, the resistivities are affected by inevitable differences in the leaching, drying and carbonization phenomena. For this reason it has also been found difficult to determine empirically the change of resistance caused by immersion in solutions of known concentration. Attempts to measure the individual samples first after immersion in distilled water, to dry them and to submerge them subsequently in the solution did not succeed, owing to the interfering effects.

Under these circumstances a linear extrapolation method is suggested for determining the approximate mean resistivity ρ_{c0} of distilled water impregnated specimens, when their resistivities at given solution concentration are known. For a given type of coating it can summarily be assumed that within a small range of concentrations, say in the order of 1:10, the electrical conductivity is approximately proportional to the total amount of solids dissolved in the mortar pores. The respective total amount of ions comprises those that were originally present in the coating as well as the additional free ions derived from the impregnating solution. If the amount of the additional ions is assumed to be proportional to the concentration of the impregnating solution, the resulting conductivity must change linearly with the conductivity of the solution. The chemical reactions, capillarity effects and all the other phenomena developing in the pores are thereby assumed to integrate into a linear resultant.

When no statistically derived mean resistivities are known for the various concentrations of the electrolyte, as in the present case, the required conductivity σ_{c0} can be roughly estimated from two limit values. For this purpose the conductivities σ_e of samples 1 to 8 listed in Table 3, have been plotted in Figure 12 versus the conductivities σ_m for a limited range of concentrations, between 0.1 to 2.0 percent NaCl. The mean values obtained for a given concentration are interconnected by the broken train of lines A, B, C, D. If the section B,C is eliminated, as improbable in view of its negative gradient at rising brine conductivities, the extensions of sections A,B and C,D intersect with the σ_e axis in points

42.5×10^{-6} and 68.5×10^{-6} mho/cm.

Upon inverting these values, it may be said that the expected mean resistivity ρ_{c0} of the eight samples for distilled water impregnation does not exceed the range between 14,600 and 23,500 ohm.cm.

Initial coating resistivities measured in practice have been found to be in the order of

$$\rho_c = 10 \times 10^3 \text{ to } 40 \times 10^3 \text{ ohm.cm}.$$

If these values are compared with the coating resistivities computed from the field data of operating concrete lines

$$\rho_L = 120 \times 10^3 \text{ to } 2{,}000 \times 10^3 \text{ ohm.cm},$$

the range of resistance increase factors is

$$\rho_L/\rho_c = 3 \text{ to } 100.$$

Thereby it should be noted that the lines concerned were buried in soils of various grades of corrosivity for a period exceeding three years.

The fact that mortar absorption figures are in no way sufficient for determining the insulating qualities of a coating makes routine insulation tests on coating samples essential. For production tests the proposed arrangement can be simplified by placing a metal guard ring on the inner wax partition instead of the electrolyte channel (Figure 13). The iron electrodes used for the electrolysis tests can be substituted by stainless steel. When using DC for the resistivity tests the top electrode should be made anodic to avoid gas interference. Measurements must be started immediately after switching on the current in view of the high gradients of the resistance curves in their initial stages. With low frequency AC apparatus, as used for ground resistance measurements, the reading can be greatly simplified.

The method described offers possibilities for the development of a portable coating insulation tester for measurements *in situ*, say on SP5 cylinder type prestressed concrete pipe. A spring loaded pad saturated with conductive solution will establish the contact to the outer surface of the coating, while the steel core will be bonded to the other pole. The method should prove useful for the detection of incipient cracks during the hydrostatic test. It also appears indispensable for coating inspection on old lines.

Mechanism of Protection

Summarizing, the following phases of the galvanic process can be distinguished at the steel surface of a mortar coated pipe.

A. Basic Conditions

Passivity owing to the alkaline reaction of the mortar; at pH > 10.

Natural open circuit potential in the order of—200 mV to a copper-sulfate reference cell.

All rust and loose mill scale has been dissolved and precipitated in the mortar.

B. Incipient Corrosion

Galvanic conditions or impressed potential differences produce on the steel surface anodic and cathodic regions.

In anodic zones: iron goes superficially into solution; current is discharged; the pH is lowered.

Iron oxide compounds are produced in the form of a dense cement skin over the steel reinforcement.

The open circuit potential, Φ, becomes less noble (i.e., numerically larger). The voltage drop caused by discharge currents numerically reduces Φ to the measured resultant potential.

TABLE 3—Initial Coating Resistivity of Samples Used for Electrolysis Test

Sample No.	Absorption Factor, Percent	Electrolyte NaCl, Percent	Polarity of Top Electrode	Resistivity ρ_c ohm.cm	Conductivity γ_c 10^{-6} mho/cm
1	6.8	0.1	+	22,400	44.6
2	6.6	0.1	—	17,400	57.5
3	6.9	0.5	—	14,100	71.0
4	6.6	0.5	+	11,800	84.7
5	6.5	1.0	+	14,600	68.6
6	6.9	1.0	—	13,600	73.5
7	7.0	2.0	—	11,800	84.7
8	6.6	2.0	+	16,400	61.0
9	6.6	5.0	—	35,800	28.0
10	6.8	5.0	+	21,100	47.4

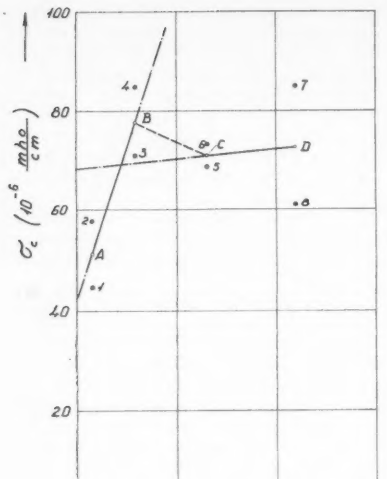


Figure 12—Linear extrapolation of the initial coating conductivity for sample impregnated with distilled water.

In cathodic zones: alkali metal ions are concentrated as current is introduced: the pH is raised.

The resultant potential becomes less noble than the respective open circuit potential due to voltage drops caused by the incoming currents.

C. Intermediate Stage

In anodic zones: the cement skin forms a protective barrier of increasing strength.

The ohmic coating resistance rises up to an asymptotic final value.

The resultant potential assumes values of numerically less than —500 mV, thus still remaining nobler than on bituminous coated lines.

In cathodic zones: the ohmic coating resistance asymtotically approaches an ultimate value.

At high contents of sodium or potassium the bond strength may be impaired by excessive impressed current densities.

D. Passivation or Breakdown

In anodic zones: a state of equilibrium is reached thanks to the cement skin and the increased ohmic resistance.

Alternatively, in the case of a serious fault in the coating or under extremely corrosive conditions, the cement skin breaks down. Ferric iron compounds are formed in form of red-brown rust, which leads to destruction of the coating.

In cathodic zones: under normal conditions a balanced state of alkalinity is maintained, without deleterious effects on the coating.

At high contents of Na and K, however, excessive current density causes a cumulative increase of alkalinity which eventually leads to disintegration of the mortar.

Corrosive Conditions

Ground Resistivity

The fact that the mortar absorbs up to and over 10 percent of electrolyte from its environments makes this type of coating particularly sensitive to low resistivity soil. The specific water retention of the ground is under these circumstances of basic importance. In the rainless season sandy soil may be dry down to three meters depth, whereas clay retains its humidity under a cover of as little as 0.30 m.

Furthermore the salt content of the mortar is also increased by diffusion and ion migration. In the anodic current discharge zones, chloride and sulfate ions migrate towards the steel reinforcement, while the pickup currents carry the alkali metals Na, K, and probably also Ca, to the cathode. The effect of the ions thus introduced into the mortar is the same, as if they were present in its ingredients, the sand or the make-up water. The presence of chloride ions reduces the inhibitive effect of the hydroxides. The electrical resistivity is lowered, possibly, by the creation of highly soluble calcium chloride. The chlorides also impair the building up of the cement skin. As a result, the discharge currents increase rapidly, causing a further accumulation of conductive ions.

Under these conditions the usual grading of soil resistivities is not applicable to cement mortar coatings. A value of 500 ohm.cm on water saturated samples is already considered very corrosive, and in soils of less than 200 ohm.cm, cement mortar must be protected by a reliable dielectric membrane.

Sulfate Attack

In view of the relatively small thickness of the coating the existing criteria for permissible sulfate contents must be conservatively applied. With reference to the recommendations of the U. S. Bureau of Reclamation,[4] moisture saturated soil should always be assumed on water lines, with regard to possible leakage at tappings and valves. A sulfate content of 150 parts per million in a saturated water extract constitutes, therefore, the upper limit for noncorrosive soil, and 1000 ppm are considered as very aggressive. Thereby it should be noted that 1000 ppm of sulfates alone reduce the soil resistivity to less than 350 ohm.cm.

The mechanism of the attack in sulfate rich soils is still subject to investigation. In the few cases where pipes were damaged, the mortar was found to be of full strength after periods of 3 to 6 years in soil of up to 7000 ppm sulfate contents. On the other hand unusual cracking of the coating was observed, exceeding 0.1 mm in width, in both axial and peripheral direction. There was every reason to assume that the attack had started through existing hair-line cracks which were gradually enlarged by sulfate action. Anion migration still further increased the sulfate contents. The creation of the protective barrier was thus delayed until corrosion with ferric oxide products started spreading over the reinforcement. This lead to a general loss of bond by volume expansion, accompanied by a series of additional cracks. A chemical analysis of the mortar verified this approach: 650 ppm of sulfate were found at the corroded steel surface, as against 40 ppm in other parts of the coating.

Special cement, to ASTM type 5 specification, is used for sulfate soils. Its 28 days' strength satisfies standard requirements, provided the cement is of adequate quality. Different type cements should not be used for adjacent sections of a concrete structure, as potential differences are liable to develop on the reinforcement. Voltages of 30 to 40 mV have been measured by Evans[5] between electrodes embedded in concrete of different cements, as against 20-30 mV found between points of the same mix. In prestressed concrete pipe with non-embedded steel cylinder, the cylinder constitutes an impermeable partition between the coating and the concrete core. There is, therefore, no objection to using antisulfate cement for the mortar coating only.

Other Effects

Hydrogen sulfide, H_2S, heavily attacks the coating. It may be found under anaerobic conditions at the crossing of old sewage lines or in the vicinity of septic pits in populated areas. Carbon dioxide contained in the soil appears to be harmless or even beneficial, as it supports the formation of impermeable calcium carbonates.

Variation of the hydrogen ion concentration in the soil between a pH of 6.0 and 9.0 can be disregarded. The local composition of the ground, vegetation or the presence of fertilizers are usually the cause of such changes. But deviations beyond the above range should be investigated. The presence of highly corrosive environments, such as a derelict refuse dump, can be detected in this way.

In addition to the chemical agents mechanical erosion must be taken into account at river crossings and in areas of flooding. Full precautions are necessary, as a single eroded spot could, at the low resistivity of water saturated mortar, seriously endanger the pipe.

The passage of AC current has no influence on cured coating, except by heating. It has been experimentally proved[3] that the insulation resistance of cement mortar remains practically unaffected by the flow of alternating current.

Under normal conditions ageing is beneficial to the coating of underground lines. The decrease of alkalinity due to loss of calcium hydroxide and the other effects of ion migration are fully compensated by the steady rise of insulating resistance.

Galvanic Currents

In arid areas the galvanic ground circuits are governed by the moisture contents of the soil. Owing to the considerable permeability of cement mortar the anodic sections usually coincide with ground regions of higher moisture content. A water flow, agricultural irrigation or a leaking blow-off of a water main may

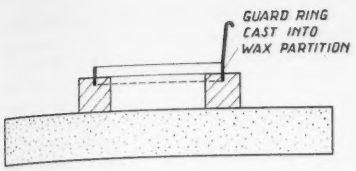


Figure 13—Arrangement of metal guard ring for resistivity measurements.

be the cause of these high moisture zones. The reduced spreading resistance of the current paths in the ground as well as the initially low coating resistivity facilitate the development of discharge currents.

It should be noted that the electrolysis effects described until now necessarily involve the presence of a metal electrode in the mortar. The mere impression of an electric potential difference over a homogeneous coating has at most a "leaching" effect. The mobile ions are swept through the mortar, without producing a significant change in its physical properties. Only when an electrode is embedded, such as the steel cylinder of a prestressed concrete pipe, an ion congestion takes place with the ensuing electrolytic phenomena.

Preventive Measures

Soil Tests

Systematic soil tests in the early stages of line planning enable the selection of a suitable route with properly graded anticorrosion measures. The soil tests consist of preliminary surface resistivity measurements, sampling boreholes, resistivity measurements on samples and chemical analyses. Results are related to water saturated extracts in order to obtain a solid basis of comparison. As previously explained, moisture saturated soil shall be assumed for the corrosivity grading on water lines.

Table 4 gives a corrosivity schedule adapted to the specific conditions on cement coated pipe. The stringent requirements with respect to chloride contents are in accordance with the low soil resistivity figures. Each column of the corrosivity schedule must be considered independently. A resistivity of 150 ohm.cm, for example, indicates severe corrosivity, even though there may be only 400 ppm of sulfate contents and 1200 ppm of chloride. Some additional soluble salts or colloidal matter are in this case probably lowering the resistivity figure.

In arid areas saline ground water is sometimes found at small depth, perched over impermeable strata. Subterraneous drainage of the trench is considered in such sections, or the line is lifted above ground level under cover of an embankment.

Constructional Precautions

A number of preventive measures are required to keep the mortar coating safe. For prestressed concrete pipe these provisions are particularly important in view of the small steel cross-sections involved and the eventual susceptibility to stress corrosion damage.

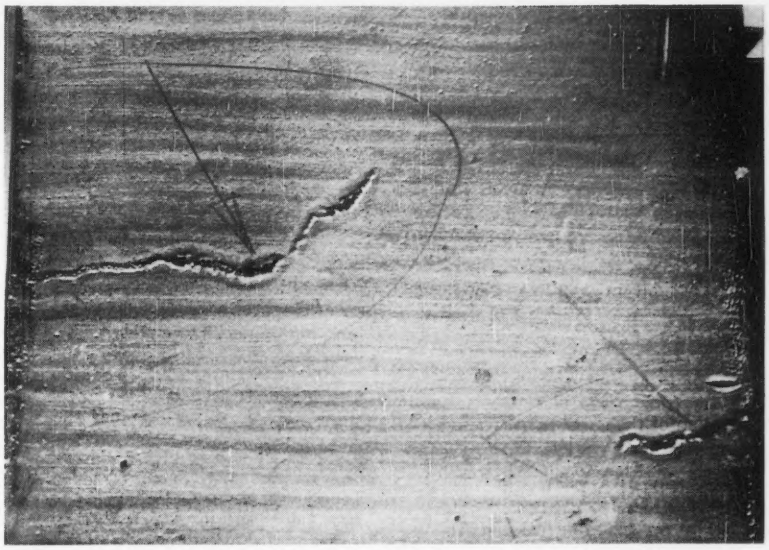


Figure 14—Insulation test on 0.05 mm thick coating of asphalt emulsion covered with 0.04 mm bituminous aluminum paint at 260 V AC. Note flash-over traces from one inch diameter electrodes to edge of plate.

The salt contents of the aggregates used for the mortar must be kept at a minimum; sulfate and chloride contents to be currently watched. Application of calcium chloride as an accelerator is not permissible. Chemical additives offered for improving the impermeability, in general, adversely affect the setting properties or the mechanical strength of the mortar. Blast-furnace cement is to a higher degree sulfate resistant than portland cement, but on the other hand, it lowers the half-cell potential of the reinforcement.[6]

In order to promote the creation of cement skin, a priming coat of pure portland cement slurry is placed over the reinforcement. The slurry is 0.5 to 1.0 mm thick, depending on the diameter of the pipe. It must be immediately followed by the mortar. The strength of a brush-sprayed mortar coating is limited by the facilities of consolidation. It can hardly exceed a thickness of four centimeters. The minimum thickness over projecting edges at welding seams or over free tails of the tension wire determines the insulation strength. Such projections as well as all accessory plates or rods left over from production should, therefore, be carefully eliminated. Embedded cylinder type prestressed concrete pipe to SP 12 standard is in this respect safer than the nonembedded cylinder, SP 5 type, owing to the complete insulation of the prestressing coils.[7]

The means for eliminating interior galvanic circuits were discussed in an earlier work.[2] Galvanic ground currents are limited by proper coating technique and the insertion of insulating joints. Resistance bonding for coordination purposes is advisable on electrically continuous lines only.[7] Embedded cylinder pipe without continuity bonds should be kept clear of other underground structures. Whenever this is impossible, insulating joints and some additional coating should be considered.

Mortar cracking due to excessive tensile stresses is prevented by careful design and precautions against water hammer. Adequate curing eliminates differential "crazy-cracks." Thermal expansion cracking is reduced by whitewashing the pipe surface. In arid areas prolonged open storage must be avoided, unless facilities for regular watering are available. Production schedules should, therefore, be closely coordinated with current construction requirements.

Bituminous Coating

In corrosive soil bituminous coating is placed over the mortar to improve the initial insulation resistance. A well penetrating primer is used to impregnate the pores and any eventual hair-line cracks at the pipe surface. Bituminous solutions or a hot bituminous membrane are applied over the primer, with a coat of whitewash for thermal protection.

Coal tar or asphalt base primers are used. Coal tar has in addition to its low water absorption the advantage of being applicable in strongly alkaline soils. It gives also a good bond owing to its phenolic components. For cutback asphalt primers suitable solvents must be chosen to obtain proper penetration. On brushed coating with an absorption factor of 9 percent, local surface penetration of two millimeters depth has been attained. Asphalt emulsions are used for wet surfaces, after curing or in rainy weather; but these emulsions have a very much smaller insulating resistance. Surface acting agents of the amine group have recently been proposed for the application of cutback asphalts to wet concrete. Generally it should be noted that the primer bond depends very much on the roughness of the pipe surface. Compacting methods should, therefore, not be intended to render a smooth finish.

One or two upper coats are applied over the primer. In a hot climate, with ambient temperatures of up to 40 C

TABLE 4—Tentative Soil Corrosivity Grading for Cement Coated Pipe

Degree of Corrosivity	Sulfate, ppm	Chloride, ppm	Resistivity, ohm.cm	pH
Moderate	0–150	0–300	1000 and above	6.0–9
Positive	150–1000	300–1500	1000–200	See note 3
Severe	Over 1000	Over 1500	Below 200	5 > pH > 10
				See note 3

NOTES:
1. Concentration limits are for saturated water extract.
2. Any one of the factors listed above is sufficient for indicating the maximum degree of corrosivity.
3. The causes of hydrogen ion concentration beyond 6 > pH > 9 are to be considered.

blown asphalt of the following characteristic is used:

Softening Point (ring and ball): 115 C;
Penetration, at 25 C: 15.

Bituminous cutback paint suffers in the sunshine from heavy blistering caused by expansion of the air occluded in the mortar pores, despite whitewashing. Therefore the paint must be applied in the field, shortly before laying the pipe. Under extremely corrosive conditions special provisions are necessary. At a sulfate content exceeding 10,000 ppm for example, as encountered in the desert of the Dead Sea approaches, two layers of hot asphalt membrane were placed over a cutback primer, with inert soil used for lining and backfilling the trench.

For the intermediate thermal protection of the concrete a bright, reflecting coating had to be found, which would adhere well to the concrete and be fully compatible with the cutback primer to follow. A bituminous aluminium paint, containing 25 percent aluminium powder by weight, though useful, did not appear suitable due to its electrical conductivity. In insulation tests carried out on 15 cm square coated sheet iron samples with a bituminous undercoat, the current regularly found its way over a shunt path along the aluminum coating (Figure 14). Satisfactory results were obtained in experiments with white Portland cement placed over the concrete for thermal protection. The cement rendered a good bond for both the concrete and the bituminous primer. It was applied in form of one of the known concrete paints or as neat cement processed into a colloidal slurry. But watering appears preferable for thermal protection, as the open mortar pores facilitate penetration of the bituminous primer.

The previously described resistivity tests were introduced for a practical evaluation of the insulating properties of bituminous coating. A composite resistance was thereby measured, comprising the continuous bituminous coat, the impregnated surface layer of the mortar sample and the remainder of the mortar thickness soaked with NaCl brine. Measurements were carried out on 2.5 cm thick brushed mortar plates of 6 to 9 percent absorption. The plates had been painted under normal working conditions with a primer and one upper coat. The following resistance ratios were obtained with respect to unpainted samples of the same batch:

Coal tar paint with filler: 5 to 10
Cutback asphalt: 3 to 5
Asphalt emulsion with filler: 1 to 2
Bare mortar sample: 1

The wide range of resistances measured on each of the materials is characteristic for painted mortar coating. The deviations are due to the lack of homogeneity in the mortar, atmospheric conditions and unavoidable differences in the paint application. Heat performance and adhesion of the various layers were qualitatively checked by raising the temperature of the samples to 60 degrees C. Thereafter the samples were immersed in a 2 percent brine at room temperature, for the remainder of the day. This cycle was repeated 10 to 20 times, unless early signs of deterioration were detected.

Much care is required to protect the bituminous coating from mechanical damage. The backfill must be free of stones. Rubber lined tracks and belt type crane loops are used for handling the pipe. On 108 inch pipe, asbestos wrapping is applied over part of the periphery, to avoid possible damage in handling.

Criteria for Cathodic Protection

Protective Voltage

A newly laid cement coated line has an open circuit potential of the order of —200 mV to a copper sulfate half-cell. Even though the resulting pipe to soil potential of old lines is seldom more negative than —500 mV, this value by no means represents the least noble open circuit potential. In spots of damaged or broken-down mortar as well as over sections of bituminous coating, the open circuit potential may reach —800 mV, as on any corroding bare steel surface.

From the above it follows that in accordance with the basic principles of electrical drainage, a potential of —850 mV is required for complete protection. At a numerically smaller value, say at —600 mV, the normally cement coated parts would still be protected. But steel surfaces deprived of the inhibiting cement atmosphere or incidentally left bare, would be subject to considerable corrosion: they would act as sacrificial anodes participating in the protection of the cement coated sections.

With —850 mV for complete protection a numerical increase of the pipe to soil potential is necessary of the order of 600 mV, as against possibly 300 mV for bituminous coating. A large part of this potential difference, however, arises out of the remarkable polarization effects under the mortar coating. At a polarization voltage of 250 mV, full protection can be achieved with a transversal IR voltage of about 350 mV. Partial protection, with a resulting potential of —600 mV, is attainable at a transversal IR drop of 100 mV.[7]

Preliminary impressed current tests should be conducted on lines which have been in the ground for not less than one year. The initial ageing process of the coating is then completed on each of the line sections under the varying conditions prevalent throughout the year. In design estimates based on earlier tests, empirical factors must be introduced for the voltage rise expected with the increase of coating resistance.

Current Densities

Other criteria proposed for complete cathodic protection of steel lines are either practically inadequate or consist of empirical figures not applicable to the present case. The known graphical determination of the protective current from the break in experimentally obtained logarithmic polarization curves, though successful in the laboratory, appears to be inconclusive. Even in the case that the respective critical current density would have been correctly determined by field tests, it must still be considered as an average for a whole line section. The characteristic break of the plotted curve depends on the composite effect of all anodic and cathodic regions simultaneously acting on the line, and not on the conditions at the weakest spot. Therefore, in most of the cases a much higher potential probably will be required for complete protection.

The protective current density values, as recommended for the various applications of electrical drainage, must be derived from the potential criterion. Assume, for example, that for a potential of —850 mV in the middle of a span, the IR component of the transversal leakage voltage amounts to

$$U_{L2} = 300 \text{ mV}.$$

For the range of unit conductances G, given in an earlier work[7] for prestressed concrete pipe with non-embedded cylinder and ¾ inch thick mortar coating,

$$G = 3000 \text{ to } 30{,}000 \times 10^{-6} \frac{\text{mho}}{\text{m}^2},$$

the respective minimum, net current densities follow

$$j_2 = G \cdot U_{L2} \left(\frac{\text{mamp}}{\text{m}^2}\right),$$

$$j_2 = 0.9 \text{ to } 9 \frac{\text{mamp}}{\text{m}^2}.$$

The mean current density for the whole span can be computed from this expression by means of the respective attenuation constant.

Limiting Factors

The maximum current density should be determined in the vicinity of the drainage point. In checking this value, the presence of detrimental alkali metals at the cathode must be taken into consideration, as electrical drainage is principally applied in soil of high salt content. Referring to the previously given data, it can be assumed that a maximum current density of the order of 10 mamp/m² will not endanger the bond strength of the coating. This appears to be borne out by the unpublished tests of

Rohwedder and Shanks, the results of which have been cited in a recent work.[8] Pending a further statistical verification of the present approach every precaution should be taken not to exceed the proposed maximum current density.

Under these conditions the complete protection of prestressed concrete pipe, at —850 mV, appears practicable. Excessive overpotentials can be avoided by reducing the length of protective spans and a suitable design of ground beds. Furthermore long protective spans would, at the high attenuation of the lines, lower the drainage efficiency.

Summing up, the following criteria are proposed for the cathodic protection of cement mortar coated lines:

—850 mV to a copper sulphate half-cell are required for complete protection.

—600 mV will probably protect the mortar coated parts only; broken down and bituminous coated sections of the line remain unprotected.

Overprotection at drainage points is to be reduced by careful design.

Conclusions

1. Portland cement coating owes its protective value to the following factors:

a. Corrosion inhibiting properties

b. A noble half-cell potential

c. Self-sealing effect

d. Rise of insulation resistance with the ageing of the line.

2. The electrolytic process has been reproduced in solutions of different concentration.

3. A method of coating resistivity measurements has been suggested.

4. Preventive planning is required for the protection of cement coated lines.

5. Cathodic protection, if necessary, must be adapted to the particular conditions.

6. Mortar coating is especially suitable for large diameter pipe owing to its positive ageing features.

Acknowledgment

Acknowledgment is made to E. Balaban, Head, Design Office, Water Planning for Israel, Ltd., for permission to publish this paper. Appreciation is expressed to the Yuval Gad Company for the data supplied, to K. Taussig, Chief Chemist, for his valuable advice and to E. Klein and the staff of the Chemical Laboratory for the analytical tests.

References

1. E. B. Rosa, Burton McCollum and O. S. Peters. Electrolysis in Concrete. U. S. Bureau of Standards, Techn. Paper No. 18, Washington, 1913.
2. M. Unz. Intrinsic Protection of Water Mains. *Corrosion*, **12**, No. 10, 526t-532t (1956) October.
3. G. Mole. The Effects of Electrolysis Upon the Strength of Reinforced Concrete. The British Electrical and Allied Industries Research Association, Report O/T3, 1948.
4. U. S. Bureau of Reclamation. Concrete Manual, p. 12 and p. 40. Sixth Edition, Denver, 1955.
5. R. H. Evans. Application of Prestressed Concrete to Water Supply and Drainage. *Proc. Inst. of Civil Engineers*, London, Part 3, **4**, p. 725-753; Discussion, p. 753-775 (1955).
6. R. M. Berthier. La Corrosion des Armatures . . . et les Procédés Préventifs. Centre d'études et de recherches de l'industrie des liants hydrauliques, Publication Technique No. 48; Paris, 1951.
7. M. Unz. Cathodic Protection of Prestressed Concrete Pipe, *Corrosion*, **16**, 289t-297t (1960) June.
8. R. F. Stratfull. Progress Report on Inhibiting the Corrosion of Steel in a Reinforced Concrete Bridge. *Corrosion*, **15**, No. 6, 331t-334t (1959) June.

Any discussion of this article not published above will appear in December, 1960 issue.

Thirty Years' Experience With

Silicate as a Corrosion Inhibitor In Water Systems*

By HENRY L. SHULDENER and SIDNEY SUSSMAN

Abstract

The development of a simple, economical proportional liquid feeding device for distributing sodium silicate in domestic water pipes permitted effective and widespread use of this inhibitor. For the past 32 years it has been used for protection of galvanized iron, galvanized steel, yellow brass, and copper water piping in thousands of buildings in East Coast cities which have corrosive water supplies.

Properly controlled, silicate treatment has eliminated rusty water, maintained satisfactory flow rates, and minimized failures due to pitting and to clogging by corrosion products. Comparative field experiments have demonstrated its effectiveness.

Most cases of poor results when using a silicate inhibitor have resulted from improper feeding by dosing methods, piping defects, poor plumbing design or fabrication, or improper operation of the water system, particularly with respect to lack of hot water temperature control.

Studies of the protective mechanism have shown that it involves formation of a thin film containing both silica gel and an absorption compound of silica and the metal hydroxide. Further basic studies are desirable for understanding the respective roles in protective film formation of alkalinity and silica in natural waters as compared to those in added silicate. 5.8.2

Introduction

SMALL CONCENTRATIONS of sodium silicate were first added to potable waters during the 1920's. Speller[1] suggested this be done to control corrosion of galvanized steel pipe in domestic water systems. Thresh[2] in Great Britain first suggested it as a means for minimizing the health hazard resulting from the solution of lead from lead piping, and later as a means for controlling corrosion of ferrous piping.

Speller's suggestion led National Tube Company to sponsor research by Texter at Mellon Institute[3] and by Russell at M.I.T.[4] which demonstrated the effectiveness of sodium silicate in reducing corrosion rates of steel.

Solid silicate was first used and was applied to the water by means of a drip or by-pass type of feeder.[4,5] With this type of feeder, silicate addition took place whether or not water was being consumed. High concentrations of dissolved silicate accumulated in the vicinity of the feeder at times of low flow and resulted in the development of difficultly removable silicate deposits which caused partial or complete clogging of the piping. These experiences with deposit formation near the point of application caused silicate treatment of water to acquire a poor reputation.

The early workers[3,5] also reported that the silicate treatment was effective for only a limited distance from the feeder. Speller placed this limit at 100 to 200 feet of piping.[6] This conclusion was definitely related to the drip method of feed used initially. The formation of deposits near the point of application depleted silicate available for protection of the piping. Since subsequent developments eliminated this problem, Speller omitted this limitation in later editions of his book.[5] In fact, later studies at Paignton, England, showed that the silicate was protecting a main at a distance 17 miles from the point of application and throughout the town distribution system.[7]

Despite these early handicaps, the method was soon applied in New York, Boston, Pittsburgh, and Great Britain. The primary goal in these installations was the elimination of "red water" (rusty water) and silicates proved most effective for this purpose.

Speller[5] at an early date recognized the limitations of solid silicates for water treatment. These materials were virtually insoluble in cold water, thereby limiting the application of the method to hot water systems. Speller expressed a hope that a convenient means would be found for the controlled feeding of liquid silicates so as to extend the utility of the method.

This was accomplished five years later by the development of the Chemistat,[8] a simple, economical, proportional liquid feeding device which finally made possible the use of liquid silicates for corrosion control in both cold and hot water piping systems in buildings without fear of buildup of silicate deposits. Experience with controlled silicate feeding soon showed that it was possible to avoid formation of such undesirable accumulations while permitting the formation of a thin, self-healing, protective film which did not build up on itself. The application of this feeder in buildings, as well as the use of proportionating pumps in the treatment of large municipal water distribution systems, showed that corrosion could be inhibited at very considerable distances from the point at which the silicate was introduced into the piping.

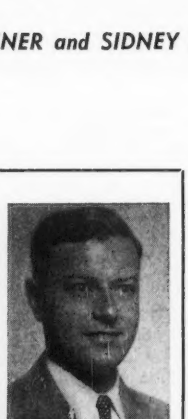
Although the first use of sodium silicate in water systems was directed at eliminating red water or lead pickup and only indirectly at reducing the corrosion of steel, during the intervening years this additive has also been shown to be an effective corrosion inhibitor for galvanized iron, galvanized steel, yellow brass, copper, and aluminum. It is currently being applied for protection of piping in many thousands of residences, apartment buildings, offices, hospitals, laundries, and hotels. Some municipal water distribution systems in Germany, Great Britain, and the United States are silicate-treated for corrosion control. In this country the method is employed for corrosion control in smaller communities, such as Hollywood, Florida; Lebanon, Pennsylvania[9]; Ossining, New York, and many others. Silicates are not used more often for corrosion control in large water systems because of the economic disadvantage when compared to the use of the less expensive lime.

Industrially, sodium silicate is commonly applied as a corrosion inhibitor to protect piping carrying zeolite-softened water, particularly in commercial laundries, and has been added to oil field brines for protection of piping and to water filled gas holders. There is also some use of silicates for corrosion protection of water tanks on shipboard and of the cooling systems of inboard motors on boats.

Theoretical

Conflicting views have been expressed regarding the mechanism by which

Shuldener



Sussman

HENRY L. SHULDENER is President and Technical Director of Water Service Laboratories, New York, N. Y. He holds a 1920 BSChE from New York University's School of Engineering and is a licensed professional engineer in New York. His whole professional life has been devoted to water treatment and corrosion prevention. Mr. Shuldener has invented several chemical feeding devices, published many technical articles and is a member of Association of Consulting Chemists and Chemical Engineers, ACS, NACE, AIChE, AWWA, Electrochemical Society, and other organizations.

SIDNEY SUSSMAN is chief chemist for Water Service Laboratories, New York City. He has a BS from Polytechnic Institute of Brooklyn and a PhD from Massachusetts Institute of Technology in 1937. Before joining his present employer in 1949 he was employed by the DuPont Company, the Permutit Company and Liquid Conditioning Corp. His principal work is in corrosion control in water systems. He has written many technical papers and obtained several chemical patents. Dr. Sussman is a member of NACE, ACS, AWWA and other technical groups and was first president of Metropolitan Water and Wastes Society.

★ Submitted for publication November 30, 1959. A paper presented at a meeting of the North Central Region, National Association of Corrosion Engineers, Cleveland, Ohio, October 20-22, 1959.

sodium silicate minimizes the corrosion in water piping. Early experiences with over-dosing by means of drip feeders led many to believe that the protective layer was a reaction product of the silicate with the hardness of the water and, therefore, that the ultimate buildup of a heavy scale with resultant clogging of pipes must be expected. This view was soon discredited,[6] although not eliminated in the minds of some people. Even to this day despite the many years of contrary experience since proportional feeding of silicate was introduced, this view in some cases still persists.

Some observers have believed that the major effect of the silicate derived from neutralization of dissolved carbon dioxide by its alkali content. In recent years, investigations by Duffek and McKinney,[10] and by Eliassen and co-workers[11] have established that much greater protection is obtained when the pH of a particular environment is adjusted by addition of a silicate, than when it is adjusted to the same final pH by addition of an alkali alone in the absence of any silica.

Fundamental studies by Lehrman and Shuldener[12, 13] have shown that the protective silica film does not begin to form until there are some corrosion products of the metal present, thus confirming a mechanism suspected many years before by Speller.[8] The corrosion products form an adsorption compound with silica, removing the latter from solution. Chemical analyses of the protective layer show that it is high in silica. The silica gel-like structure of the film makes it semi-transparent when wet. When dry, it is visible as a thin coating slightly colored, either brown by iron corrosion products or white by zinc corrosion products.

As soon as the thin surface film of adsorption compound forms, further corrosion of the metal surface virtually stops. Because no further corrosion products form, no additional buildup of the film takes place. This mechanism explains why such a film is self-limiting in thickness.

It also explains why the protective film is self-healing when damaged. If the film is removed from a surface by any means, the metal begins to corrode and a fresh surface film forms by reaction with the silica present in the treated water. This, of course, indicates why it is necessary to treat such systems continuously.

Since red water consists of iron oxides in suspension, the fact that the silicate precipitates these in a film on the surface of the piping as fast as formed, explains the great effectiveness of silicate treatment in overcoming red water problems.

Further studies on the mechanism of silicate inhibition are being carried out currently in several laboratories in the United States and Great Britain.

Application

For feeding silicates in large industrial and municipal applications the various types of proportional feed pumps are used.[7, 14]

The widespread successful application of sodium silicate as a corrosion inhibitor in piping systems of apartment buildings, office buildings, hotels and similar structures which are characterized by wide fluctuations in the rate of water use and limited maintenance personnel, would have been impossible without the development of a simple hydraulic-type proportional feeder with no moving parts.[8] This type of feeder, a picture of which is shown in Figure 1, is connected across an orifice inserted in the water line, applying the Venturi principle to feed treatment chemical in proportion to the flow of water.

A cross sectional view of the feeder, shown in Figure 2, indicates how the heavy, viscous sodium silicate solution is present as a separate layer in the lower part of the tank. The water entering the feeder through the inlet impinges upon the water-silicate interface, picking up a small amount of silicate which is carried back into the water line. Tracer studies with a glass hydraulic proportioning feeder and a colored inlet stream show that, following this impingement, the diverted water returns to the top of the tank and flows to the outlet. Thus the silica pickup is independent of the total interface area.

It will be seen from the above description that the amount of silicate solution entering the water line is proportional to the total flow of water so that uniform treatment is maintained under variable flow conditions. When no water is flowing in the line, no treatment chemical enters. The proportioning feeder is always connected below the water line and, therefore, it is impossible for any silicate solution to flow by gravity into the water line.

Because neither inlet nor outlet lines dip into the silicate solution, there can be no pickup of strong chemical from the feeder during any period of low pressure or even negative pressure in the water main. Additional pickup of chemical should there be sudden and heavy reversal of flow in the main is prevented by a baffle inserted just below the outlet line. Independent tests made by the New York City Department of Water Supply, Gas and Electricity demonstrated the correctness of these statements and, as a result, the Department permits installation of this feeder on potable water lines without check valves or vacuum breakers.

In general, it has been found most suitable and economical to utilize the common commercial grade of liquid silicate having a density of 40°—42° Baume and an alkali to silica ratio of 1 Na_2O:3.22 SiO_2. Using this silicate, effective control of red water and of corrosion can be obtained under normal operating conditions by addition of sufficient silicate to increase the silica content of the water by approximately 8 ppm. In some cases it is desirable to increase the initial dosage in order to more rapidly establish a protective film, and in some cases it is possible to reduce the average dosage somewhat and still to maintain the protective film once it has been established.

When applying a chemical to a potable water system, the question of possible overtreatment of the water must be considered. In New York City,[15] Detroit,[16] and Yonkers, New York, application of chemical treatment to potable waters within buildings is regulated by specific codes, and approval of the chemicals and feeders by the municipal authorities is required.

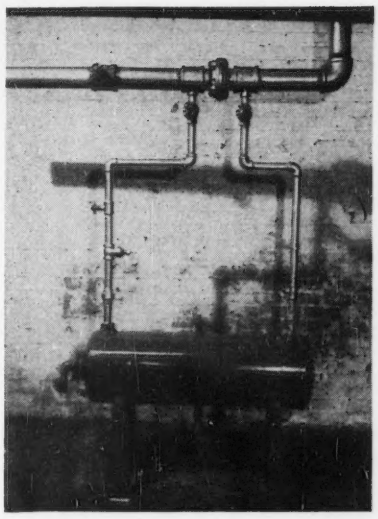


Figure 1—The Chemistat, a hydraulic proportioning feeder, installed across an orifice inserted in a water main for feeding sodium silicate.

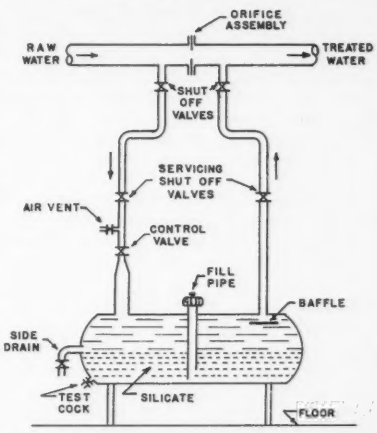


Figure 2—Cross-section of the hydraulic proportioning feeder showing the interface between the treatment chemical and the water layers, and other details of the feeder assembly.

Field Results

Since 1927 Water Service Laboratories has provided a corrosion control service using sodium silicate as the inhibitor for protection of domestic water piping in large apartment houses, hotels, hospitals, and office buildings in the New York, Philadelphia, and Washington Metropolitan areas. More than 400 large buildings have been treated continuously for more than 10 years and about 50 have been treated continuously for more than 25 years.

Most of the waters being treated are surface supplies, but silicate treatment has also been effective on a number of well supplies which, while much harder

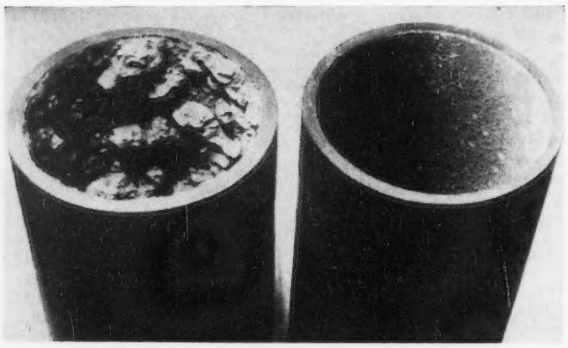


Figure 3—Four inch galvanized iron cold water line from Philadelphia office building. Tuberculated section was in use for two years before silicate treatment of the water was started. The smoother section replaced this when water treatment was started and was in service for an equal length of time.

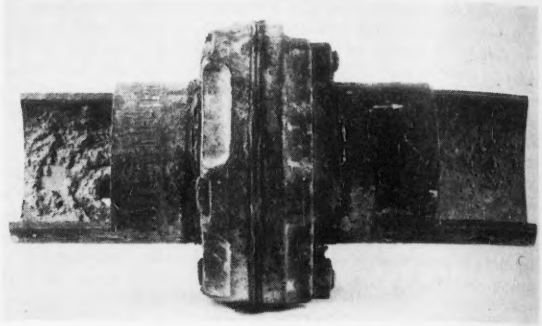


Figure 4—Orifice disc assembly taken from a 15 year old hydraulic proportioning feeder installation in New York City. Note tuberculation of galvanized iron main on the inlet side where no added silicate was present and absence of significant tuberculation on the outlet side where the added silicate entered the water stream.

and containing more natural silica, are aggressive by virtue of their high carbon dioxide content. Table 1 shows some typical analyses of waters being treated.

Several real estate management companies have kept statistical records for a period of years with regard to the development of leaks and to repair costs on groups of buildings using the same water supply. Some of the buildings were being treated with sodium silicate and others were not. These statistical studies have shown that application of silicate treatment is economically justified on the basis of savings in re-plumbing costs. Numerous other case histories have been cited by Stericker[14] of the effectiveness of silicate treatment in minimizing corrosion.

TABLE 1—Typical Analyses of Waters Silicate-Treated for Corrosion Control*

PROPERTY		LOCATION AND SOURCE				
		Atlantic City N.J.	New York N.Y. (Catskill)	Philadelphia Pa. (Schuylkill)	Jamaica N.Y.	Idlewild N.Y.
		Surface & Well	Surface	Surface	Well	Well
pH		5.5	6.9	6.9	6.8	6.9
Total Hardness	(as $CaCO_3$)	13	20	153	308	1650
Calcium	(as $CaCO_3$)	6	14	89	124	900
Total Alkalinity	(as $CaCO_3$)	6	10	48	218	444
Free Carbon Dioxide	(as CO_2)	High**	3	12.5	68	100+
Chloride	(as Cl)	10	4	23	20	2150
Sulfate	(as SO_4)	11	8	101	95	350
Silica	(as SiO_2)	6.5	2.5	8	24.5	30
Total Solids		41	31	257	421	4640

* Analyses before treatment. All values, except pH, are in ppm.
** Includes organic acidic materials.

Housing Development Study

Thirty years ago rusty water and poor flow conditions appeared in the galvanized wrought iron hot water system of an apartment house development consisting of 54 large buildings on Long Island. The insurance company which owned and operated this development carried out a comparative test in three adjacent buildings. After installing long test sections of new galvanized iron piping, the water in the first building was not treated, that in the second building was treated with sodium silicate applied by building personnel by means of a drip feeder, and that in the third building was treated by a regular water treatment service by means of a hydraulic proportioning feeder.

Test pieces of the new pipe were removed at yearly intervals and examined by an independent consulting laboratory. After only one year, test pieces from the first two buildings were coated with a thick, rust-colored coating containing about 14 percent iron oxide and were moderately pitted beneath the coating. The test piece from the third building, at which the silica had been proportionately fed by the hydraulic feeder, was coated with a thin tan coating containing only 4 percent iron oxide and beneath which was found only a slight degree of pitting.

After four years the corrosion rate in the piping of the third building was less than 25 percent of that in the piping of the other two buildings. At this time serious difficulties became manifest in the hot water piping systems of the many untreated buildings and silicate treatment of the hot water was started in all 54 buildings of the development.

Ten years later, serious flow troubles developed in the untreated *cold* water lines and silicate treatment was started after substantial piping replacements were made.

Silicate treatment of the hot water permitted the owners to defer total re-piping until the development was twenty-six years old, although at nine years of age, when silicate treatment was started, the hot water piping was in such condition that normal experience in the area indicated that general re-piping would be required within a few years. Thus, the silicate treatment extended the life of this piping from an estimated additional three or four years without treatment to seventeen years with treatment.

AISI Study

An extensive independent field study of the effectiveness of silicate as a corrosion inhibitor was undertaken by the Committee on Steel Pipe Research of the American Iron and Steel Institute.[17] This was done at another large housing development in Brooklyn, New York, which had been built during World War II with galvanized steel piping. Periodic examinations of test specimens removed from both hot and cold water lines in treated and nearby untreated buildings were made over a period of 17 years. No trouble has been encountered from red water or reduced flow in any of the treated buildings, except for a few short nipples of small diameter supplying kitchen sinks. These difficulties were caused mainly by collected sediment. This was in contrast to normal experience with such pipe carrying New York City water. Rusty water and major pipe replacement in hot water systems are common within five to ten years on this supply.

The tests showed that untreated cold water lines had a greater corrosion rate than treated *hot* water lines. Over the period of the test, pitting was deeper in the untreated cold water lines than in the treated cold water lines.

Qualitative observations made during this test indicated that some tubercles formed fairly rapidly during the early years, but then tended to flatten out. Similar observations have been reported from silicate-treated municipal water systems in Germany.[18] There is, however, no basis to claims sometimes made that silicate treatment of a water will remove existing rust deposits.

Comparative Pipe Specimens

Figure 3 shows sections of cold water line exposed for two years in a Philadelphia office building. The tuberculated section of this 4 inch pipe had been in use for two years with no water treatment. It was replaced by the other section of pipe at the time that silicate

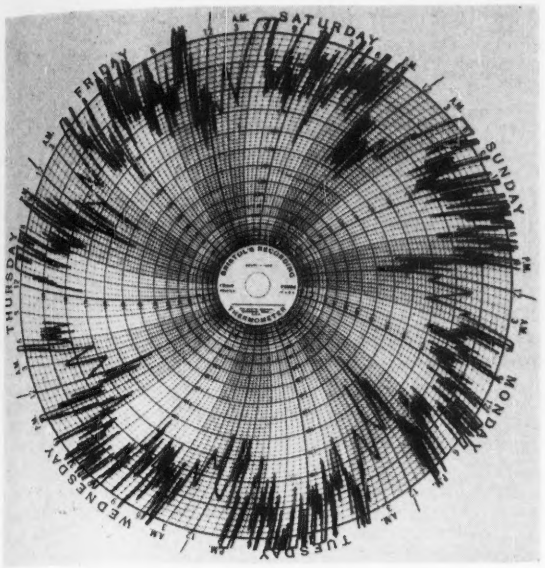


Figure 5—Hot water temperature recorder chart showing poor temperature control at an apartment house. Note the wide and frequent fluctuation, and temperatures as high as 210 F.

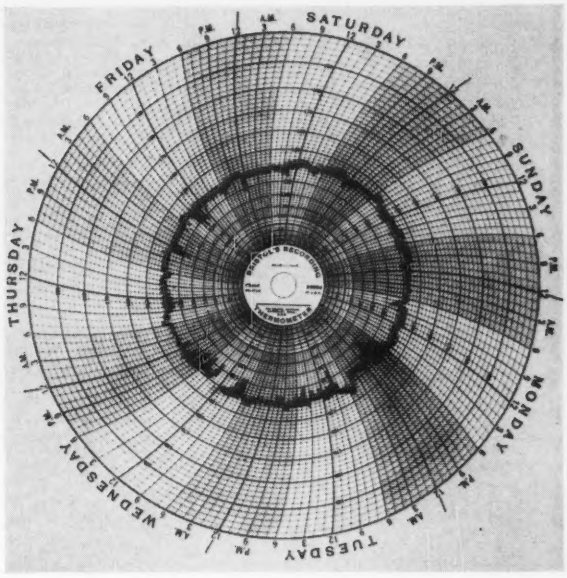


Figure 6—Hot water temperature recorder chart showing very small deviation from 140 F at apartment house with properly adjusted thermostatically controlled mixing valve, and hot water generating and distributing equipment in good working order.

treatment was started and this new section was removed for evaluation after it had been in service for two years. The difference between the tuberculated appearance of the specimen exposed to untreated water and the reasonably smooth coating on the specimen exposed to treated water is made even more apparent by the rust color of the former and the light tan of the latter.

A striking example of the effects of silicate treatment can be seen in Figure 4 which shows an orifice disc which had been in use for 15 years in New York City diverting untreated cold water to the hydraulic proportioning feeder described above. Note the heavy tuberculation of the main at the untreated inlet side and the superficial rust coating at the treated outlet side.

Degree of Protection

Several attempts have been made to evaluate quantitatively the degree of protection afforded to steel pipe by silicate treatment of water. By measurement of the dissolved oxygen content of water entering a test pipe and that of the water leaving the test pipe, Russell[4] estimated that the corrosion rate was reduced 50 percent in cold water lines and 80 percent in hot water lines by silicate treatment.

On the basis of the iron content of water after passing through a test section of steel pipe, Stericker[7] estimated that silicate treatment reduced the corrosion rate of steel by 73 percent.

Hudson and Wormwell[19] reported results of a test carried out in the piping system of an English school. Coils of steel wire were cleaned and weighed before and after insertion in sections of the hot water piping system of one building. In the absence of water treatment, corrosion rates in the range 12 to 30 mils per year were found. When the silica content of the water was increased by 15 ppm, the corrosion rate was reduced to 3.7 mils per year. This corresponds to a reduction of 82 percent in the average corrosion rate of the steel in untreated water, and is a surprisingly good agreement with the above data obtained by other, indirect methods.

Non-Chemical Influences

Poor results obtained with silicate treatment of waters are usually caused by non-chemical factors. These may be related to the original design or construction of the water piping system, to the quality of piping materials, or to operating conditions. This subject has been discussed at some length by Shuldener.[20]

Typical of poor construction was the case of a hot water storage tank which pitted through at the top within six months because a layer of air was trapped in the upper section as a result of the outlet pipe having been screwed down an inch into the tank instead of being flush with the top.

Poor quality of piping materials is illustrated by the common occurrence of skips, flaws, inclusions, and pinholes in galvanized pipe. These help to localize corrosion when water and temperature conditions are such that potentials of the zinc-iron system are reversed.[21, 22]

Probably the most important operational factor tending to counteract the protective effects of silicate addition is excessively high hot water temperature. Not only is 140 F a practical water temperature ceiling from the viewpoint of hazards to people, but higher temperatures accelerate the corrosion process, making it increasingly difficult for any given inhibitor dosage to protect metals as temperature rises.

Temperature fluctuations normally associated with overheating cause expansion and contraction of the piping. This results in leaks at joints due to excessive strains, and flaking off of old rust deposits forming rusty water, developing local stoppages by sedimentation in small diameter branch lines, and accelerating corrosion by exposing fresh metal which behaves anodically. Rusty water thus formed leads users to run large volumes of water to waste in the hope of getting clean water. This can overload the hot water generator and aggravate an already bad operating condition in a continuing vicious cycle. Such temperature fluctuations are shown on a temperature recorder chart from the domestic hot water system of a building in which poor control permitted the hot water to reach 210 F at times (Figure 5). In contrast, Figure 6 shows a temperature recorder chart from a domestic hot water system in which the hot water temperature was thermostatically controlled at about 140 F.

These observations emphasize that silicate treatment of water is not a cure-all and is no substitute for good design, good construction, and good operation of a water piping system.

Summary

Thirty years experience with silicate as a corrosion inhibitor in water systems of large buildings has shown that it provides a simple, safe, and reliable method for eliminating red water and minimizing corrosion in domestic water piping whether it be galvanized, brass, or copper. The experience has also shown that silicate treatment is not a cure-all and cannot be depended upon to overcome the handicaps introduced by poor design, poor construction, or poor operation.

References

1. F. N. Speller. *Journal of the Franklin Institute*, 193, 519-520 (1922).

2. J. C. Thresh. *Analyst*, 47, 459-468, 500-505 (1922).
3. C. R. Texter. *Journal of the American Water Works Association*, 10, 764-72 (1923).
4. R. P. Russell. Publications from M.I.T., Vol. 61, No. 69, Pub. Ser. No. 369, 4pp. (1926) Feb.
5. F. N. Speller. *Corrosion—Causes and Prevention*. 1st Ed., McGraw-Hill Book Co., New York (1926), p. 353.
6. F. N. Speller. *Chemical Age*, 32, 457 (1924).
7. W. Stericker. *Industrial and Engineering Chemistry*, 30, 348-351 (1938).
8. H. L. Shuldener. U. S. Patent 1,796,407 (March 17, 1931).
9. U. S. Public Health Service. Municipal Water Facilities, p. 30 and 118 (December 1956).
10. E. F. Duffek and D. S. McKinney. *Journal of the Electrochemical Society*, 103, 645-648 (1956).
11. R. Eliassen, R. T. Skrinde, and W. B. Davis. Birmingham Technical Meeting, American Iron and Steel Institute, October 15, 1958.
12. L. Lehrman and H. L. Shuldener. *Journal of the American Water Works Association*, 43, 175-188 (1951).
13. L. Lehrman and H. L. Shuldener. *Industrial and Engineering Chemistry*, 44, 1765-1769 (1952).
14. W. Stericker. *Industrial and Engineering Chemistry*, 37, 716-720 (1945).
15. New York City Health Code, Section 141.07 (1959).
16. A. J. Dempster. *Journal of the American Water Works Association*, 45, 81-88 (1953).
17. Committee on Steel Pipe Research, American Iron and Steel Institute, Progress Report PR-104—L.
18. G. Seelmeyer. *Gesundheits Ingenieur*, 75, 69-71, No. 3/4 (1954).
19. J. C. Hudson and F. Wormwell. *Chemistry and Industry*, 1957, 1085.
20. H. L. Shuldener. *Corrosion*, 10, No. 3, 85-90 (1954).
21. R. B. Hoxeng. *Corrosion*, 6, 308-312 (1950).
22. H. L. Shuldener and L. Lehrman. *Journal of the American Water Works Association*, 49, 1432-40 (1957); *Corrosion*, 14, 545t (1958).

Any discussion of this article not published above will appear in December, 1960 issue.

10-Year Index to Corrosion Magazine

An alphabetical subject and author index of the first 10 years (1945-1954) of CORROSION is available. A chronological table of contents of each issue is included. Write to CORROSION, National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas.

Effect of Composition and Heat Treatment On the Stress Corrosion Cracking Of Austenitic Stainless Steels*

By E. E. DENHARD, JR.

About the Author

E. E. DENHARD, JR., is senior research engineer with Armco Steel Corp., Baltimore, Md. He has a BS from Purdue University and MS from Johns Hopkins University. He is a member of the ASM, NACE, ASTM, Electrochemical Society and Maryland Institute of Metals.

Abstract

A grooved, tensile type, accelerated stress corrosion test is described by which austenitic stainless steels were tested in both the solution and the vapor phase of boiling 42 percent magnesium chloride. Of the commercial alloys tested, Types 310 and 314 stainless steel offered considerably greater resistance to cracking than the more commonly used 304, 316 and 347 grades. These grades not only showed longer times to crack for the same applied stress but indicated higher threshold stresses below which cracking would not be expected to occur. Resistance to cracking increased with both nickel and silicon content but was generally unaffected by carbon, nitrogen, manganese and chromium contents within commercial limits.

Variations in heat treatment and surface conditions were relatively ineffective in changing the cracking times of austenitic stainless steels. Treatments designed to apply on oxide film showed some improvement in the resistance to cracking of these alloys.

The data suggest that stress corrosion cracking in these alloys is both electrochemical and mechanical in nature, probably closely related to the deformation characteristics of the alloys and, to a lesser extent, the passive film which protects them. 6.2.5

Introduction

ACCELERATED TESTS to determine the possible susceptibility of a metal to stress corrosion cracking are routine procedures for many laboratories and investigators. Such tests can be justified on the part of the design or materials engineer who is charged with evaluating materials for a particular application and on the metallurgist who is interested in developing more resistant materials.

Over the years a wide variety of such tests have been performed on many alloy systems. This has resulted in a vast accumulation of data, very little of which lends itself to direct comparison. In the special field of stress corrosion cracking of austenitic stainless steels, this seems to be especially true; a survey of the literature indicates that tests have been made using every conceivable type of sample, method of applying stress and selection of corrosive media. This is not so say that all tests should be conducted in one manner, nor that other environments should not be investigated. But it is somewhat disconcerting to realize that in the hundreds of tests performed, there is very little published information describing the results of tests on the entire stainless steel family of alloys under uniform and reproducible testing conditions.

Probably the closest approach was made by Scheil[1] as reported in the 1944 Symposium on Stress Corrosion Cracking of Metals, but even here the comparative tests were performed largely at one level of applied stress.

It would seem desirable to have such information for comparative material selection purposes. For example, is annealed Type 316 with an applied stress of 30,000 psi more or less resistant to chloride stress corrosion cracking than sensitized 304 with an applied stress of 10,000 psi. A further question one might ask is which of the standard AISI stainless grades exhibits the maximum resistance to this type of attack.

An aspect of the stress corrosion cracking of austenitic stainless steels that seems to have been neglected is a systematic study of the effect of variations in individual elements. Possibly minor adjustments or additions would greatly enhance the resistance of these alloys to this type of attack.

Case histories of stainless steels that have failed by stress corrosion in field service repeatedly show that unexpected and early failures in one instance are paralleled by perfectly satisfactory performance in another while operating under apparently identical conditions and with the same alloy. It has been speculated that the condition of the steel surface prior to use might be a controlling factor in such erratic performance.

The present paper was prepared to provide some answers to these general problems. For this reason it is divided into three major sections: (1) Comparative stress corrosion resistance of commercial alloys and the effect of heat treatment and surface conditions, (2) The effect of variations in composition on resistance to cracking, and (3) Observations on the initiation of cracking.

Finally, it would be amiss not to compare these observations with some of the present-day theories on how stress corrosion cracking occurs.

Experimental Procedure

Early in the program of the author's company's investigation of stress corrosion cracking it became evident that a reliable and standard test procedure would be required if a large number of commercial and experimental alloys were to be examined.

Some of the test specimens considered were simple beams loaded in the center, cantilever beams, direct tension, hydrostatically loaded tubes, stamped markings, torsion samples and many others with which the reader is undoubtedly familiar.

The first approach was to use simple beams. This seemed the most inexpensive and expedient manner to test large numbers of samples for screening purposes. In this test a strip sample is placed, electrically insulated, in a jig, and, with the ends restrained, the center portion is deflected to produce tension stresses in the outer fibers. It was soon discovered that this system did not lend itself to an accurate stress analysis. The initiation of cracks resulted in a lowering of the initial stress and, dependent upon their frequency and severity, time to failure (if indeed it could be determined) varied considerably. Secondly, it was noticed that a peculiar cracking pattern existed. Cracks were both more numerous and deeper on the edges and center region of maximum strain than elsewhere on the sample, and, while the fiber stresses could be calculated for the region of maximum deflection, it was not known how to correct for the apparently variable edge condition. Horseshoe type samples exhibited similar cracking patterns (this is discussed in considerable detail by Nahorst[2]

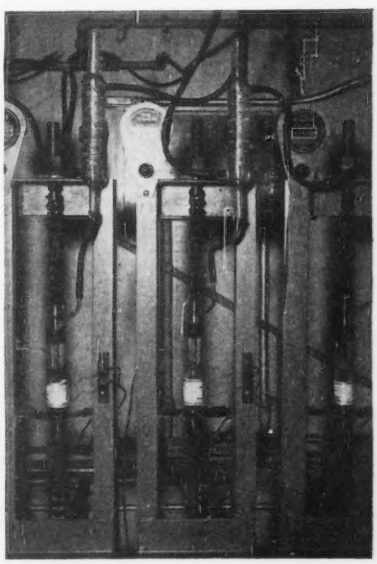


Figure 1—Close-up of stress corrosion test unit.

*Submitted for publication November 6, 1959. A paper presented at a meeting of the Northeast Regional, National Association of Corrosion Engineers, Baltimore, Maryland, October 5-8, 1959.

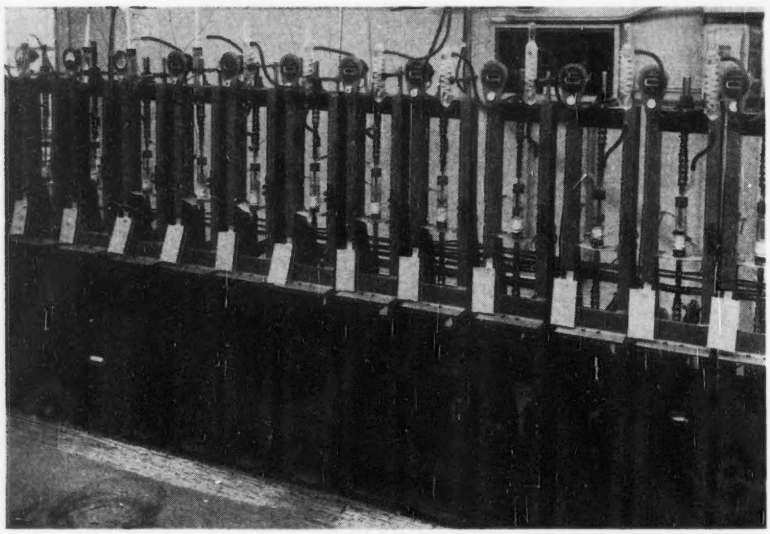


Figure 2—Battery of stress corrosion units.

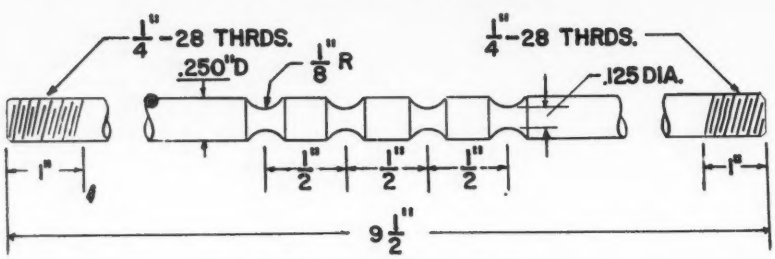


Figure 3—Stress corrosion specimen (tensile type).

in his stress analysis of this type specimen).

These observations led to a direct tension type sample in which the load was applied by dead weights through a simple lever system. Using a round wire or rod type specimen, it was reasoned that essentially uniaxial stresses would be operating. The first samples tested were 9″ long, ¼″ diameter, with a gage length machined in the central portion ⅛″ diameter by about 1″ long. The sample was completely immersed in boiling 42 per cent magnesium chloride by inserting it in a 1¼″ diameter by 6″ long open-end borosilicate tube which had a low voltage heating element wrapped around the bottom outside portion. Rubber stoppers were placed in each end of the glass tube with holes drilled in their centers to accommodate the samples. Two additional holes in the top stopper were provided for a quartz thermocouple well and an entry to a water-cooled condenser for the corrosive vapors. A close-up view of the cell assembly is shown in Figure 1 and the entire battery of test units in Figure 2. Electric timers, which were stopped when the specimen was broken by a micro switch located under the lever arm, completed the testing machine.

The decision to use magnesium chloride as the corrodent was based mainly on the fact that it was known to be extremely active in cracking the austenitic stainless steels, and because it was rather easily handled in laboratory tests. A large supply of salt was kept on hand to keep variations in composition and pH as constant as possible throughout a series of tests.

It has been found that during a test run the boiling 42 percent magnesium chloride stays at a steady 309F and requires at the most a cc of water introduced through the condenser to make up for any loss due to evaporation overnight.

In starting a new test, the salt solution was first adjusted with water additions in a large beaker over a bunsen burner, and, with tongs, poured hot into the cell through the top opening with the rubber stopper in the raised position. As soon as the solution reached the boiling point, the top stopper was lowered into place and the load applied. Timing was considered to begin upon the application of load and the test was continued until the sample cracked to failure. Once a week the boiling solution was syphoned off, the cell flushed with distilled water and a fresh batch of magnesium chloride introduced in the manner described above.

Shortly after testing was started, it was found that some steels broke outside of the gage length in the vapor phase region near the top stopper, this despite the fact that the stress was only one-fourth as high in this region. Thereafter the solution was only allowed to cover one-half of the sample, thus affording an opportunity for the sample to crack either in the solution or the vapor phase above it.

A further refinement became necessary as more crack-resistant alloys were tested and the times to fracture became intolerably long. Circumferential grooves were machined into the sample to purposely introduce multiaxial stress. Although this was done with reluctance from a stress analysis standpoint, it was felt that at least the maximum stress could be calculated since the stress concentration factor is fairly accurately determined for this particular geometry. Figure 3 illustrates the final specimen design on which the results of this paper are based. Four notches were included to provide two in the solution phase and two in the vapor phase.

In general, an alloy was tested by exposing the first sample at a stress near its ultimate tensile strength. This was followed by additional tests, usually at decrements of 10,000 psi, or until a limiting stress was found, below which fracture did not occur except in very long periods of time.

For most of the commercial austenitic stainless steels, testing was discontinued after 1000 hours. In special cases longer times were used.

Samples were prepared by machining to final size, annealing, abrasive repolishing at 000 grit, and finally electropolishing. This sequence of operations was followed to insure the minimum of residual stresses. Annealing was performed by heating the samples in an electric muffle furnace with an air atmosphere generally for a period of ten minutes at temperature and quenching vertically in a perforated tube that was immersed in water.

The material for all of the commercial alloys tested, with the exception of Worthite, was the product of an electric arc furnace heat. The Worthite was from a 1000 pound induction melt. Processing to wire size consisted of normal hot rolling, pickling, annealing and cold drawing operations. All samples were laboratory annealed.

The special heats melted to investigate the effect of the individual elements were made in a 30 pound laboratory induction furnace. The ingots were hot forged to two inch square billets and hot rolled to bar stock, generally ½″ or ⅝″ round. They were then either machined directly to ¼″ round or cold drawn to wire size followed by specimen preparation as for the commercial alloys.

Before a specimen was assembled in the cell, the root diameter of each of the grooves was measured and a record made with respect to location. The applied stress was based on the minimum diameter. The calculated true stress, based on the stress factor caused by the groove, was derived from the work by Neuber.[3] Because all of the materials were considered ductile (more than 5 percent elongation) and the geometry remained the same, a constant stress concentration factor of 1.30 was derived. This stress factor is not large but apparently was sufficient to introduce multiaxial stresses which accelerated failure. The effectiveness of the grooves can be judged by noting that Type 310 with a straight gage and an applied stress of 70,000 psi failed in 475 hours as compared to 45 hours for a grooved or notched sample at the same applied stress. Comparable reductions in

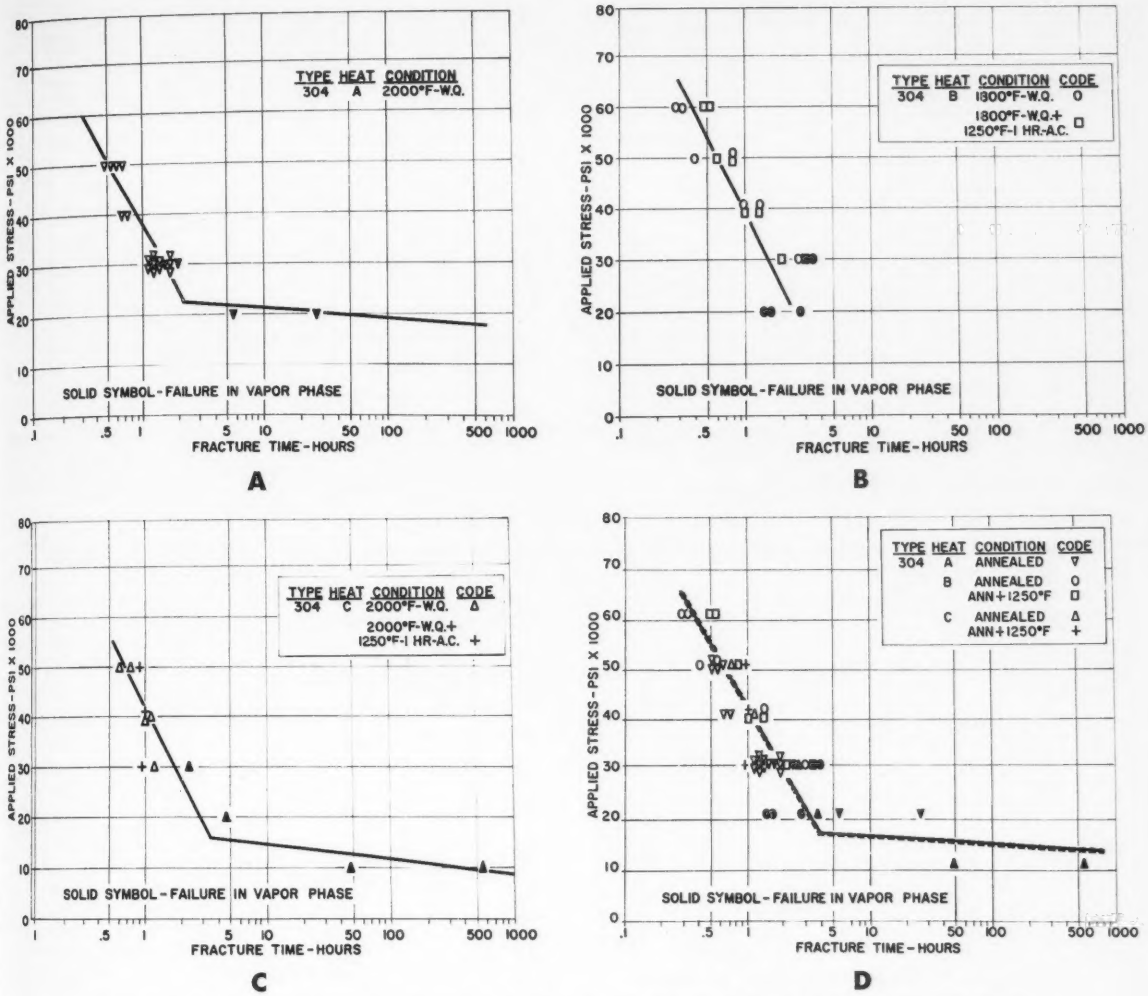


Figure 4—Tensile type stress corrosion tests on Type 304 stainless steel specimens in boiling 42 percent magnesium chloride.

fracture times were noted for other alloys tested. In this paper all stress values are given as the applied stress or nominal stress, which should be multiplied by the above factor to obtain the maximum stress. It should be noted that this relationship only holds true up to the point where the maximum stress exceeds the elastic limit.

Results of Accelerated Tensile Stress Corrosion Tests—Commercial Alloys

Table 1 contains the chemical composition of the commercial alloys tested. Worthite, Armco 17-14 Cu-Mo and Armco 17-10 P were included because they were austenitic stainless steels which contained elements considered likely to have an effect on the cracking resistance. Armco 17-10 P is an age-hardenable alloy, austenitic in all conditions, which offered a wide range of mechanical properties.

Table 2 lists the mechanical properties of the commercial alloys. Included in this table is a notched tensile stress value. These values were determined on samples which had a circumferential groove identical to those used in the stress corrosion samples.

Figures 4a, 4b, 4c and 4d show the results of Type 304 stainless steel tested in tension in boiling 42 percent $MgCl_2$ and illustrate the type of semilogarithmic curve and scatter of data obtained. Tests on this grade were conducted at four annealing temperatures, with and without sensitizing treatments. The curves are shown separately for each heat tested and then as a composite assembly. The data are presented in this form to show that heat treatment has little over-all effect on the performance of 18-8 as measured by these testing conditions, especially in relation to the other grades, as will be shown later.

Type 304, whether annealed or sensitized, exhibits comparable cracking times for equal stress applications. Cracking in both cases is transgranular.

Variations in annealing temperatures of 1800F to 2300F produced only minor changes in time to failure. This appeared however to be related to the applied stress, with the lower temperatures and finer grain size exhibiting slightly more resistance to cracking at the lower stress levels.

The results of tests on Heat B, Type 304, are contained in Table 3.

The effect of surface preparation was also investigated on heat "B." Samples were tested as machined and with various oxide films or with active pickled surfaces. The results of these tests are listed in Table 4.

Machined samples, in which it is assumed compressive stresses were present, tended to resist cracking to failure slightly more so than annealed samples that had been pickled or electropolished. It is interesting to note that as machined plus pickled samples broke in the vapor phase, possibly indicating the influence of the presence of oxygen in the cracking mechanism.

Pickling or electropolishing of machined samples appears to shorten the life of Type 304 in boiling magnesium chloride. Both processes would remove metal surface layers and conceivably reduce compressive stresses which are known to inhibit stress corrosion cracking.

Annealed samples performed best when

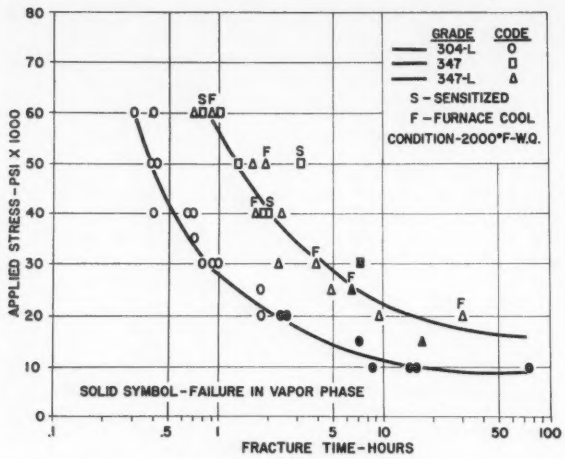


Figure 5—Tensile type stress corrosion tests on Types 304-L, 347 and 347-L stainless steels in boiling 42 percent magnesium chloride.

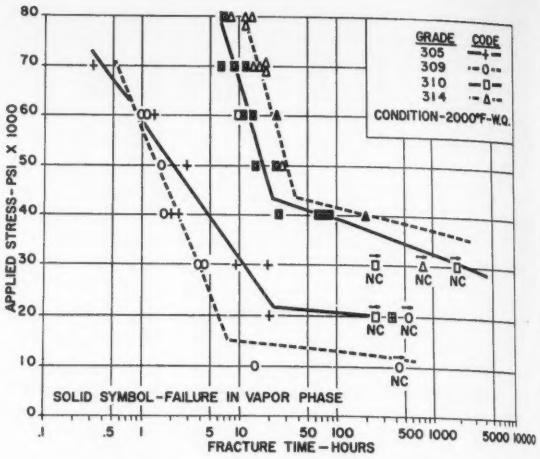


Figure 6—Tensile type stress corrosion tests on Types 305, 309, 310 and 314 stainless steels in boiling 42 percent magnesium chloride.

TABLE 1—Composition of Commercial Stainless Steels Tested in Tension in Boiling 42 Percent Magnesium Chloride

Grade	Heat	ELEMENT, PERCENT									
		C	Mn	P	S	Si	Cr	Ni	Mo	Cb	Cu
304	A	.048	1.18	.022	.011	.60	19.27	9.26	...	...	...
304	B	.052	1.29	.021	.015	.64	18.79	9.38	...	...	...
304	C	.038	.70	.026	.013	.55	18.51	9.75	...	...	...
304-L	D	.024	1.08	.020	.010	.39	18.50	9.42	...	...	...
305	E	.050	.57	.019	.013	.34	18.40	11.61	...	...	...
309	F	.070	1.77	.026	.015	.53	22.70	13.88	...	...	...
310	G	.102	1.78	.011	.006	.40	27.31	24.47	...	...	...
310	H	.109	1.94	.009	.011	.36	27.33	21.38	...	...	...
314	I	.14	2.00	.019	.008	2.25	24.80	19.66	...	...	...
316	J	.053	1.67	.024	.021	.35	17.46	13.02	2.24	...	...
316	K	.054	1.78	.024	.014	.50	17.93	12.96	2.21	...	...
347	L	.060	1.96	.017	.016	.76	17.76	10.53	...	.83	...
347-L	M	.026	1.57	.022	.013	.55	18.72	11.13	...	.31	...
Worthite	N	.030	.32	.005	.007	3.08	19.05	24.03	2.50	...	1.79
Armco 17-14 Cu-Mo	O	.062	.85	.011	.011	.69	16.74	14.34	2.53	.77	3.40
Armco 17-10 P	P	.12	.62	.27	.024	.42	16.99	10.69	...	...	...

given an oxide-forming coat treatment. An ebonized sample (black oxide) showed considerable improvement in cracking time as compared to pickled or electropolished samples.

From Figure 4d it is significant that failures after five or six hours occur in the vapor region and this points out the fallacy of total immersion tests. The only explanation offered is the probable concentration of chlorides that occurs in cracks and crevices through evaporation. It was noticed that the portion of the sample out of the solution was constantly exposed to a washing action by the steam and condensing vapors. It is conceivable that the vapors carried salt to the specimen surface and that deposits built up when the water evaporated, leaving a concentrated salt residue behind. This would seem particularly likely to occur in pits or surface imperfections.

The data suggest that a limiting stress of approximately 10,000 psi is reached below which cracking will not occur except in extremely long times. Some investigators have reported cracking to occur at stresses as low as 3000 psi[3] and others as low as 2000 psi[4], but the data reported here contradict these statements.

Type 304, like other alloys, appears to have a relatively sharp break in the stress vs time to fracture plot. With decreasing applied stress, a point is finally reached where cracking becomes less sensitive to stress and samples display increased resistance. For this reason the curves in Figures 4a, 4b, 4c, and 4d have been drawn showing a pronounced break. To accurately determine the shape of the curve in this region would require many tests and, for the purposes of this investigation, this was not considered essential.

Figure 5 illustrates the data obtained on Types 304-L, 347 and 347-L. Curved lines have been drawn through the points on these graphs in contrast to most of the other plots in this paper. These stabilized and low carbon grades offer freedom from intergranular corrosion and are frequently used in welding applications where annealing treatments are impractical. Tests on 304-L were made in the annealed condition. Types 347 and 347-L were tested in the annealed, annealed and sensitized, and annealed and "stabilized" or stress-relieved conditions.

Cracking times for each grade, regardless of condition, were practically identical. If residual stresses were present in samples annealed at 2000F to a significant degree, they would be expected to show different cracking times than samples slow cooled from 1600F which were considered to be more free from internal stresses. Apparently Type 347 stainless steel is in the same general class as Types 304 and 304-L, offering only slight improvement in resistance to cracking. Low carbon (.03 percent max.) 18-8 behaves similarly to Type 304, perhaps showing slightly shorter cracking times for a given stress than its higher carbon counterpart. This trend is contrary to the observations of Uhlig[5] who reported that 18-8 type alloys that contain .015 percent C or .01 percent N are more immune to cracking than commercial type alloys.

Types 305, 309, 310 and 314 are shown in Figure 6. It is significant that with increasing alloy content greater resistance to cracking is achieved, but perhaps of even more interest is the fact that the apparent break in the curve occurs at higher applied stresses. This suggests that there may be a threshold stress below which some of these alloys may not fail for extended periods of time, especially in applications which have been border-

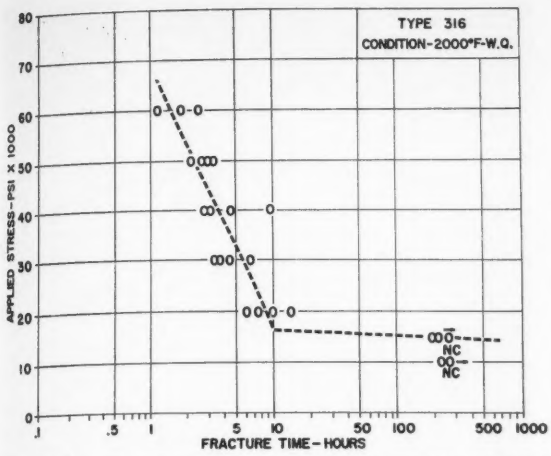


Figure 7—Type 316 stainless steel tested under tensile loading in boiling 42 percent magnesium chloride.

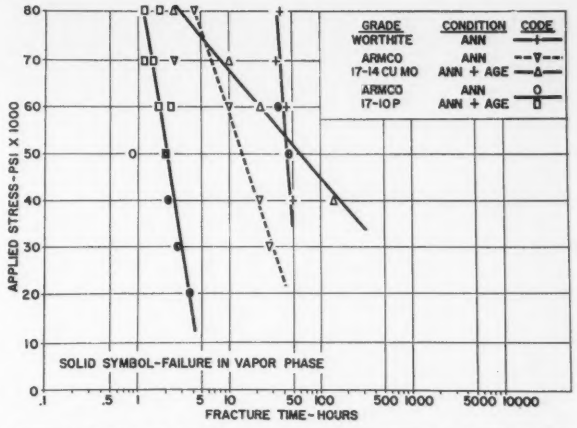


Figure 8—Results of tensile type stress corrosion tests for Worthite, Armco 17-10P and Armco 17-14 Cu-Mo. Media—boiling 42 percent $MgCl_2$.

line for less noble stainless steels such as 18-8.

Type 316, a grade widely used because of its excellent general corrosion resistance, is shown in Figure 7. This alloy compares favorably with Type 309 (25Cr—12Ni) but does not offer the protection to chloride stress corrosion cracking that its high level of general corrosion resistance would suggest.

The results of tests on Worthite, Armco 17-10 P, and Armco 17-14 Cu-Mo are shown in Figure 8.

Armco 17-10 P is interesting because this stainless steel offers a wide range of mechanical properties in its annealed and aged conditions, as shown in Table 2, and remains austenitic in both conditions.

Armco 17-10 P seemed a logical choice to check Logan's[6] proposal that stress corrosion cracking occurs as the result of micro creep, even at low temperatures, resulting in rupture of the oxide film. This rupture together with electrochemical action causes cracks to proceed on plastically deformed slip planes in suitably oriented grains. Based on the data shown in Figure 8, it does not seem likely that wide variations in the strain for a given applied stress cause any appreciable difference in cracking time.

The slope of the stress vs time curve for aged material is possibly slightly steeper than annealed material and at a higher stress level due to its ability to sustain higher loads. Tests at 50,000 psi, however, showed cracking times of 1 and 2.3 hours for annealed and aged samples respectively. This however is hardly a significant difference. Other than variations in the yield strength, the only important metallurgical change was a fine dispersion of carbides throughout the grains in the aged condition.

Armco 17-14 Cu-Mo is primarily a high temperature alloy but it has been used in many applications where corrosion resistance to sulfuric acid is important. Normally it is used in the solution treated (annealed) and aged condition which results in the optimum high temperature properties. In this condition titanium and columbian carbides are believed to be precipitated in a fine dispersion in a low work hardening matrix containing copper. This afforded an

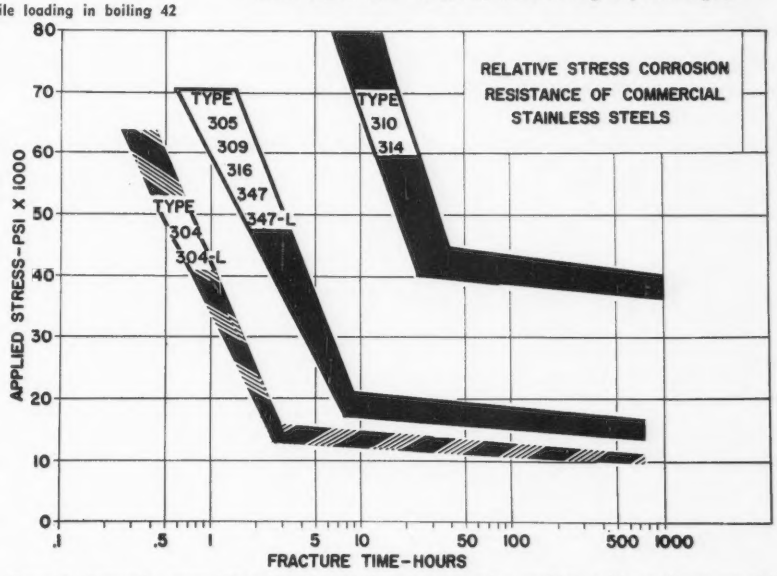

RELATIVE STRESS CORROSION RESISTANCE OF COMMERCIAL STAINLESS STEELS
TYPE 305 309 316 347 347-L
TYPE 310 314
TYPE 304 304-L
APPLIED STRESS-PSI X 1000
FRACTURE TIME-HOURS

Figure 9—Composite curves illustrating the relative stress corrosion cracking resistance for commercial stainless steels in boiling 42 percent magnesium chloride.

TABLE 2—Mechanical Properties of Commercial Stainless Steels

Grade	Heat	Treatment, Deg. F	Ult. Tens. Str., psi (Notched Sample)	Ult. Tens. Str., psi	0.2% Yld. Str., psi	Elon. 4 x D., Percent	Red Area, Percent
304	A	2000—WQ	98,100	87,500	30,800	68.0	80.0
304	B	1800—WQ	98,100	93,100	39,600	63.0	76.0
304	C	2000—WQ	98,100	84,700	27,400	64.0	80.5
304-L	D	2000—WQ	98,100	82,500	27,500	54.0	80.0
305	E	2000—WQ	98,100	80,100	30,900	66.0	76.5
309	F	2000—WQ	94,600	82,300	30,600	58.0	74.0
310	G	2000—WQ	110,500	101,600	53,100	44.0	69.0
310	H	2000—WQ	110,500	89,800	34,400	51.0	72.0
314	I	2000—WQ	114,500	98,400	45,300	55.0	72.0
316	J	2000—WQ	114,500	89,200	35,000	52.0	76.0
316	K	2000—WQ	96,000	86,300	33,100	66.0	71.0
347	L	2000—WQ	96,000	86,300	30,600	63.0	74.0
347-L	M	2000—WQ	96,000	98,400	48,400	45.0	74.0
Worthite	N	2075—WQ	96,000	84,000	45,000	64.0	75.0
Armco 17-14 Cu-Mo	O	2050—WQ	98,200	87,100	35,300	43.0	72.5
Armco 17-14 Cu-Mo	O	2050—WQ + 1350—5 Hrs. AC	98,200	88,700	37,900	42.0	67.5
Armco 17-10 P	P	2050—WQ	98,200	91,100	37,900	66.0	77.5
Armco 17-10 P	P	2050—WQ + 1300—24 Hrs. AC	98,200	137,900	87,900	28.0	42.0

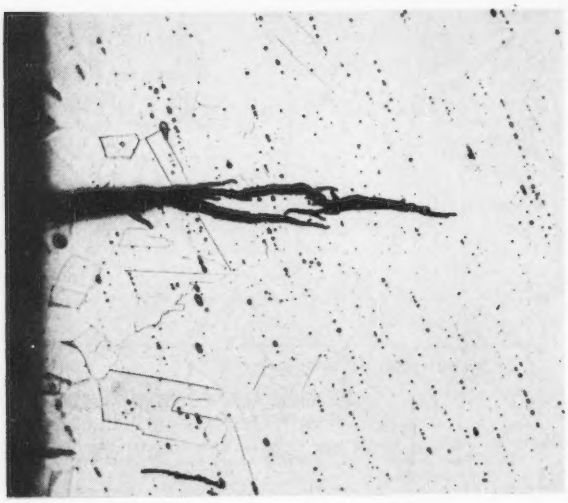


Figure 10A—Type 304, heat C-annealed 2000 F WQ. Applied stress was 40,000 psi. Fracture time was 1.0 hour in boiling $MgCl_2$. Etchant: electrolytic —50 percent nitric acid. Approximately 220X.

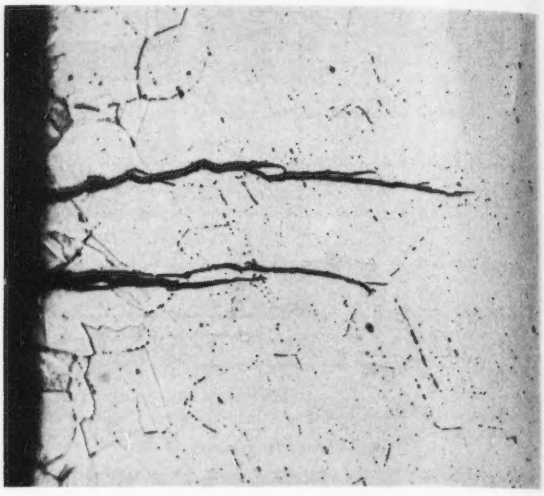


Figure 10B—Type 304, Heat C—annealed 2000 F WQ plus sensitized 1250 F—1 hour AC. Applied stress 40,000 psi. Fracture time was 1.0 hour in boiling MgCl. Etchant: electrolytic—50 percent nitric acid; magnification, approximately 220X.

TABLE 3—Effect on Annealing Temperature on Cracking Time for Type 304 Stainless Steel

Applied Stress, psi	Time to Failure, Hours, at Various Annealing Temperatures		
	1800 F	2150 F	2300 F
60,000	0.3 (2)	0.3	0.3
50,000	0.4, 0.8	0.5	0.4
40,000	1.0, 1.3	0.6	0.6

No. in parentheses indicates no. of tests.

TABLE 4—Effect of Surface Preparation and Condition on Cracking Time for Type 304 Stainless Steel

Condition	Applied Stress, psi	Phase in which Cracking Occurred	Fracture Time, Hours
(1) As machined (not annealed)	50,000	Vapor	2.1, 3.4, 1.5
(2) As machined + passivated in 20% HNO_3 + 2% $Na_2Cr_2O_7$	50,000	Both	1.4, 3.7
(3) As machined + 10 min. electropolish (duPont solution)	50,000	Solution	1.0, 0.6
(4) As machined + 10 min. pickle (10% HNO_3 + 3% HF by vol.), 80 F	50,000	Vapor	1.9, 1.0
(5) As machined + $Na_2Cr_2O_7$ at 800 F—20 mins, (black oxide coating)	50,000	Solution	1.1, 1.6
(6) Annealed (2000 F, WQ) + electropolished 7 min.	50,000	Both	0.4, 0.4
(7) Annealed (2000 F, WQ) + 10 min. pickle (10% HNO_3 + 3% HF by vol.) 80 F	50,000	Solution	0.4
(8) Annealed (2000 F, WQ) + abraded (000 grit) + soak in 5% H_3PO_4 to produce phosphate film	50,000	Both	0.4, 0.5
(9) Annealed (2000 F, WQ) + $Na_2Cr_2O_7$ at 800 F—20 mins, (black oxide coating)	50,000	Solution	3.5

TABLE 5—Statistical Study of Expected Cracking Times and Confidence Limits of Commercial Alloys

Grade	Heat No.	Stress, psi	Expected Cracking Time, Hrs.	No. of Tests	Standard Deviation, Hours	Possible Error, Percent*
304	A	30,000	1.43	16	0.332	9.5
	A	50,000	0.55	5	0.046	6.0
	A + B + C	30,000	1.35	20	0.520	14.1
	A + B + C	50,000	0.60	9	0.125	11.2
310	G + H	40,000	63.0	4	26.3	34.3
314	I	70,000	19.0	4	3.9	17.0
	I	80,000	10.5	4	2.52	19.8
316	J + K	20,000	8.8	4	3.16	29.3
	J + K	30,000	4.2	4	1.67	32.6
	J + K	40,000	3.75	4	1.15	25.2
	J + K	50,000	2.5	4	.28	8.9

* The probability is 0.9 that the average fracture time is not in error by more than ± the percent shown.

opportunity to determine the effect this condition might have on resistance to stress corrosion cracking.

Tests on this material were performed on welding wire composition material because it was readily available in ¼" wire size. This material has lower carbon and does not contain the Ti addition of normal 17-14 Cu-Mo but has slightly higher Cb. Both annealed and aged 17-14 Cu-Mo contain austenitic structures and each has a hardness of about R_b-85. This alloy offers slightly better stress corrosion resistance to boiling $MgCl_2$ than Type 316 and it is interesting to note from the fracture times that aging tends to flatten the slope of the stress vs time to failure curve. This is the reverse of the trend shown by Armco 17-10 P and suggests that a precipitate in a hardened matrix results in a steepening of the curve, whereas precipitates in a soft matrix (no age hardening) tend to flatten the stress vs time curve.

Worthite, another commercial alloy useful because of its excellent corrosion resistance, showed merit in resisting stress-corrosion cracking in boiling $MgCl_2$. This austenitic alloy was slightly superior to Type 314 at all stress levels tested and appears to be worthy of consideration where chloride cracking is a factor. Tests at lower stress levels are still in progress.

Not shown on the charts were some limited tests performed on Type 312, 29Cr—9Ni, stainless steel. The normal structure for this alloy is a mixture of austenite and ferrite and it is noteworthy that cracking occurred only in the austenite phase, carefully by-passing the bands of ferrite.

Figure 9 represents a composite stress vs time curve for all of the commercial alloys, showing their relative stress-corrosion cracking resistance. Figures 10A and 10B show typical cracking patterns of Type 304 stainless steel. Figures 11A and 11B show Armco 17-10 P; Figure 11C is Type 312 stainless steel.

Scatter and Reliability of Data

The question of reliability of the test data and expected amount of scatter was raised early in the program. It was evident that the commercial stainless steels varied considerably in their resistance to stress corrosion cracking, perhaps well enough to rate them in order of their susceptibility. However, for the second phase of the program—evaluation of individual element effects—it was thought desirable to apply a statistical analysis to

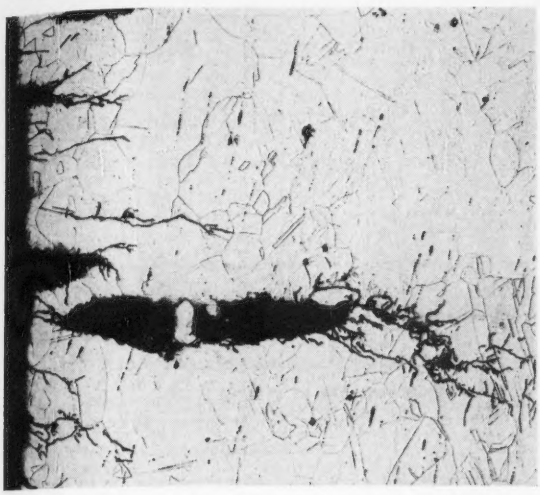


Figure 11A—Armco 17-10P, Heat P- Sol. Tr. 2050 F WQ. Applied stress was 50,000 psi; fracture time was 0.9 hours in boiling $MgCl_2$. Etchant: electrolytic 50 percent nitric acid; magnification approximately 100X.

Figure 11B—Armco 17-10P, Heat P- Sol. Tr. 2050 F WQ plus aged 1300 F 24 hours. AC applied stress 60,000 psi. Fracture time was 2.2 hours in boiling $MgCl_2$; etchant was 50 percent nitric acid, magnification approximately 100X.

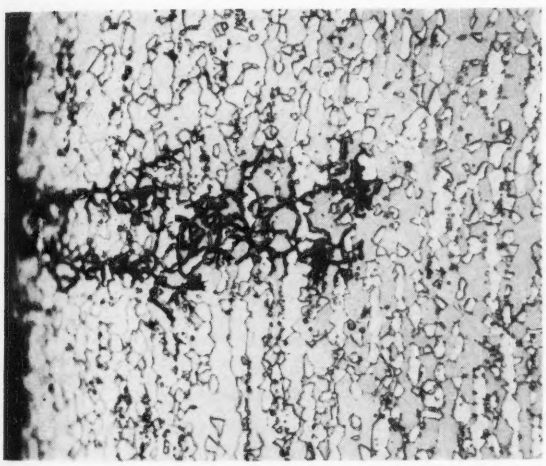


Figure 11C—Type 312, 29Cr-9Ni -annealed 2000 F WQ. Applied stress was 80,000 psi; fracture time was 1.9 hours in boiling $MgCl_2$. Etchant: electrolytic-50 percent nitric acid and NaCN; magnification approximately 430X.

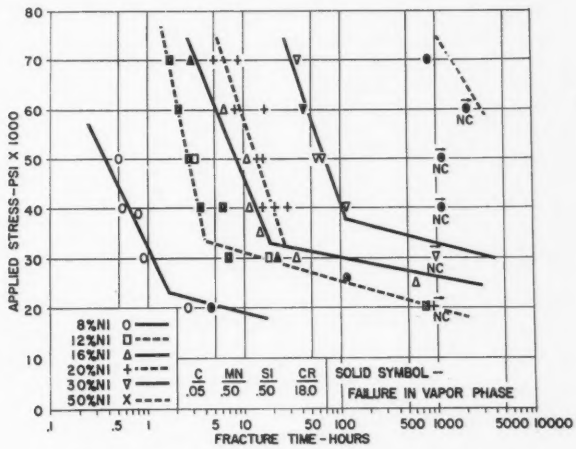


Figure 12—Effect of nickel in inhibiting stress corrosion cracking.

the commercial alloy data to know how much scatter to expect. This was accomplished by applying a graphical arithmetic probability technique described by Lewis.[7] A summary of the results is contained in Table 5.

Types 304 and 310 were selected because the times to failure for these alloys at a given stress varied considerably. Secondly, Type 304 at higher stresses generally broke in the solution, whereas Type 310 exhibited predominantly vapor breaks. It was uncertain what effect this might have on the scatter of expected fracture times.

The data show that a high degree of reproducibility can be expected for 18-8 and similar alloys exposed at high stress levels and that as lower stresses are applied, cracking times become more erratic and greater scatter exists.

As would be expected, if several heats of the same grade were grouped together, the standard deviation as well

TABLE 6—Composition of Alloys Studied for Individual Element Effect

Elements Varied	Heat No.	ELEMENT, PERCENT					
		C	Mn	Si	Cr	Ni	N
Control	R-1740	.050	.39	.41	17.97	12.18	.059
C, N	R-1821	.016	.32	.27	17.75	11.85	.032
	R-1746	.047	.46	.32	17.69	12.15	.15
	R-1820	.11	.40	.32	17.75	11.96	.035
	R-1748	.005	.25	.13	17.59	12.29	.031
Ni	R-1735	.039	.33	.33	17.70	8.11	.036
	R-1737	.041	.39	.34	17.57	16.04	.042
	R-1738	.041	.45	.38	17.50	20.07	.035
	R-1739	.038	.55	.42	17.63	30.13	.039
	R-2290	.043	.54	.74	17.64	49.92	.035
Cr	R-1742	.050	.34	.20	7.93	12.07	.022
	R-1743	.045	.41	.31	11.44	12.19	.025
	R-1444	.042	.34	.32	15.64	12.20	.029
	R-1745	.043	.33	.38	23.00	12.15	.058
Mn	R-1732	.041	.10	.32	17.84	11.51	.045
	R-1733	.047	1.69	.34	17.70	11.83	.040
	R-1734	.043	4.92	.47	17.73	11.97	.041
Si	R-1747	.041	.39	.22	17.62	12.20	.044
	R-1710	.043	.55	.92	18.10	12.38	.041
	R-1707	.052	.59	1.89	17.78	11.41	.048
	R-2341	.044	.52	2.14	18.34	11.84	.040
	R-1705	.059	.51	4.04	17.96	11.87	.031

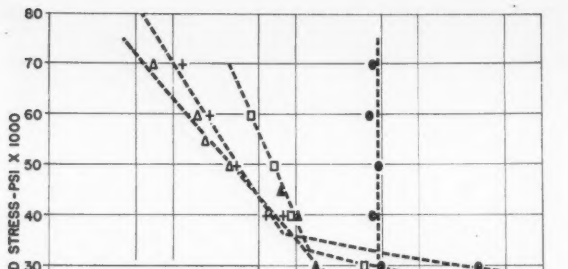


Figure 13—Effect of variations in chromium on stress corrosion cracking.

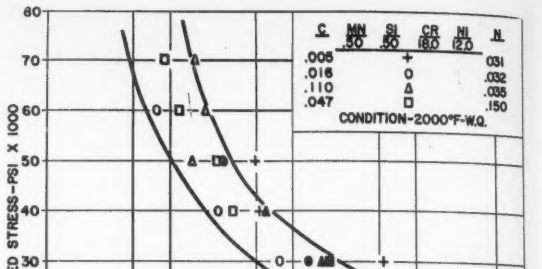


Figure 14—Effect of variations in carbon and nitrogen on stress corrosion cracking.

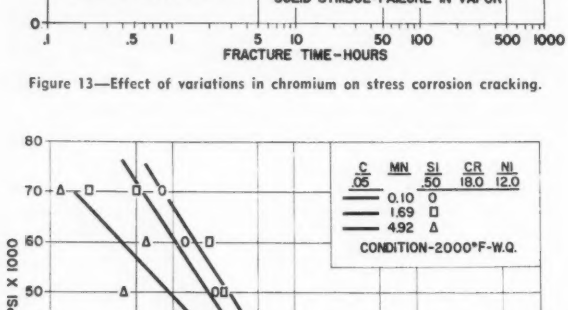


Figure 15—Effect of manganese content on stress corrosion cracking.

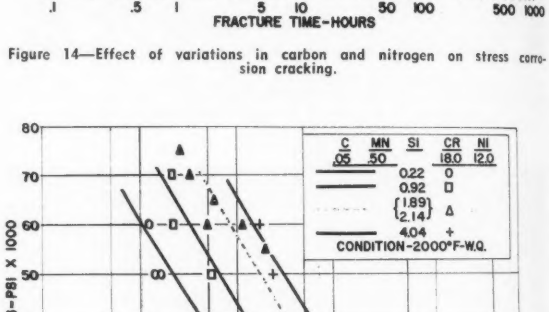


Figure 16—Effect of silicon content on stress corrosion cracking.

as the possible error in fracture time increased.

The data also show that considerably less reproducibility of test results can be expected as fracture times increase, regardless of the applied stress. This was observed on many experimental alloys that showed promise in resistance to cracking but produced erratic long time fractures. It is likely that this is an inherent part of the stress corrosion cracking mechanism. It may be noted that the possible error for Type 316 stressed at 30,000 psi showing only solution cracking is as large as Type 310 stressed at 40,000 psi failing only in the vapor region; however, differences in their cracking times make direct comparison impossible.

Results of Accelerated Tensile Stress Corrosion Tests—Laboratory Heats to Investigate Effect of Composition

The analyses of the heats melted to investigate the effect of composition are contained in Table 6. In general an 18Cr—12Ni base was used which represented a stable austenitic matrix, and the individual elements to be studied were varied. The mechanical properties of these heats are shown in Table 7.

Heat R-1740 was melted as a control heat containing .05 C, 18 Cr, 12 Ni. Unfortunately the nitrogen was slightly higher than normal, in this case .059 percent, as compared to an expected .030 percent residual. As the data will show, this did not introduce any serious difficulties.

Probably the most effective element in inhibiting stress corrosion cracking is nickel. Many investigators have observed this phenomenon and the data plotted in Figure 12 confirm this view. Copson[8] found that iron-chromium alloy containing 16-20 percent chromium and 45-50 percent nickel seemed immune to cracking in boiling 42 percent magnesium chloride. The present work parallels this finding.

Higher nickel heats such as Inconel (80 percent Ni) were also tested and found not susceptible to chloride stress corrosion cracking in boiling $MgCl_2$. A test on this alloy at 100,000 psi failed in slightly over 1000 hours but examination showed the cause to be increased stress, attributed to pitting corrosion, which reduced the cross sectional area. Stresses of 50,000 to 90,000 psi did not cause cracking in time periods up to 3500 hours.

No difference was noted in the crack formation in micro examinations of alloys with varying nickel content. All failed transgranularly with characteristic forked branching type cracks. Those that did not fail had shallow pits, which did not seem to lead to cracks. Metal loss in the vapor phase resulting from general corrosion was high for all alloys regardless of nickel content after testing times exceeded 1000 hours.

The effect of variations in chromium is shown in Figure 13. In general, with increasing chromium the stress vs time to fracture curve tends to flatten out. At 8 percent chromium the alloy transformed to martensite upon quenching from 2000F. This is reflected in the high tensile properties of heat R-1742 contained in Table 7. There was insufficient

chromium in this alloy to stabilize the austenite and it is of interest that, practically independent of stress, the samples failed in the same period of time. Cracks in this alloy were predominantly transgranular and appeared to be located in segregated regions of retained austenite.

High manganese reduced the resistance of 18Cr-12Ni alloys to cracking. Manganese, an austenite-forming element often used as a substitute for nickel, does not seem to have an additive effect to nickel in reduction of cracking propensity. The results of the tests on alloys with varying percentages of this element are contained in Figure 15.

The effect of variations in carbon and nitrogen are shown in Figure 14.

Within the composition limits of the heats studied containing carbon and nitrogen variations, little difference was noted in susceptibility to stress corrosion cracking.

Low carbon material, R-1821, produced slightly shorter cracking times at higher stresses than the control heat. Cracking occurred both in the liquid and vapor phases in this material.

High nitrogen 18Cr-12Ni failed only in the solution phase except for tests of more than ten hours duration and also appears slightly inferior to commercial Type 304.

None of the data confirm Uhlig's[5] view that the interstitial elements C and N greatly change the alloys' resistance to cracking within the limits studied in this investigation. Heats containing less than .01 percent N and less than .01 percent C and N are under study. Perhaps these alloys will show more of a trend in this direction, although a British Intelligence Report[9] in 1946 reported that 0.20 percent N in a 12Cr-12Ni steel was accompanied by increased resistance to stress corrosion cracking.

Uhlig[5] and Leu and Helle[10] have reported conflicting data on the effect of silicon additions to stainless steels. Uhlig's work indicated that silicon additions of from 1 to 4 percent were beneficial in reducing cracking, whereas Leu and Helle noted that additions of 0.3 to 3.0 percent Si increased the number of observed cracks which formed. This investigation substantiates the findings of Uhlig.

With increasing silicon, increasing time to fracture was noted as shown in Figure 16.

Observations on Initiation of Failure

The direct tensile type specimens were not suitable for metallographic study of the cracking process because of lack of flexibility in removing the sample from the solution at desired times for examination. For this reason, bent beam samples were prepared of various alloys and mounted in a jig which, after exposure to the boiling magnesium chloride, could be conveniently mounted on the microscope for examination. The jig was designed to permit accurate relocation after repeated exposures to the boiling magnesium chloride. These tests were totally immersed.

The procedure followed consisted of shearing sheet coupons .050" thick to ½" x 3". These were annealed, rough ground, hand polished to 000 grit and metallographically polished. They were then etched to delineate the grain boundaries, plastically deformed in a jig and the entire unit exposed to the boiling magnesium chloride for various time periods.

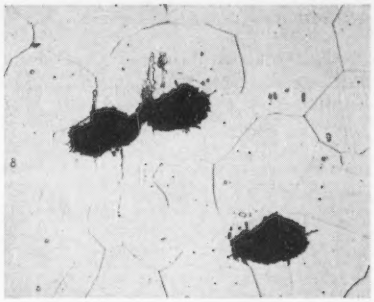


Figure 17A—Type 304, annealed 2300 F, AC. Specimen was metallographically polished, plastically stressed as bent beam sample and exposed for five minutes in boiling $MgCl_2$. Etchant, 50 percent nitric acid; magnification, approximately 375X.

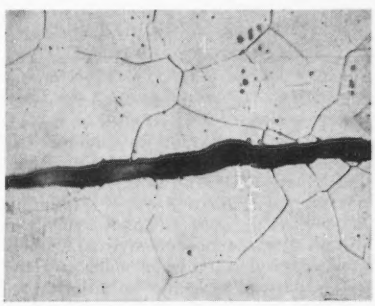


Figure 17B—Type 304, annealed 2300 F, AC. Specimen was metallographically polished, plastically stressed as bent beam sample and exposed for two hours to boiling $MgCl_2$. Etchant, 50 percent nitric acid; magnification, approximately 375X.

It was found that Type 304 showed recognizable cracks in as short a time as two minutes. Additional exposure revealed increased crack growth. Cracks predominantly started within a grain rather than at grain boundaries and they were frequently found to be associated with, or emerging from, pits.

Cracks in Type 304 after five minutes exposure are shown in Figure 17a. The cracks are transverse to the applied stress and are typical of those found in an area about ⅓ of the way in from the edge of the strip.

The effect of various annealing temperatures and times was investigated on samples of this type. Temperatures of 1900 F to 2300 F for a constant time period of 15 minutes were studied. It was found that cracks were both more numerous and severe on the samples annealed at the higher temperatures, confirming the general findings of the tensile type tests contained in the first part of this paper.

The same observation held true for samples that were annealed longer times at a given temperature.

After two hours in the boiling salt the cracks appear as shown in Figure 17b. This photomicrograph shows the corrosion products on the side of the widening crack. Nielsen[11] has proposed that the force of solid corrosion products, cathodically deposited, causes cracks in combination with applied and residual stresses. Electron photomicrographs shown by Nielsen closely resemble that depicted in Figure 17b taken on an optical microscope.

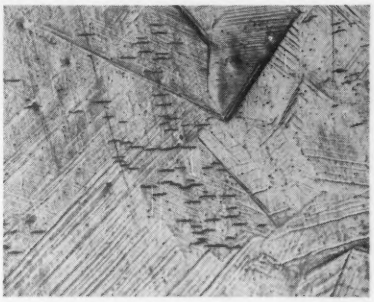


Figure 17C—Type 304, annealed 2200 F, WQ. Specimen was metallographically polished, plastically stressed as bent beam sample and exposed for five minutes to boiling $MgCl_2$. Unetched; magnification, approximately 125X.

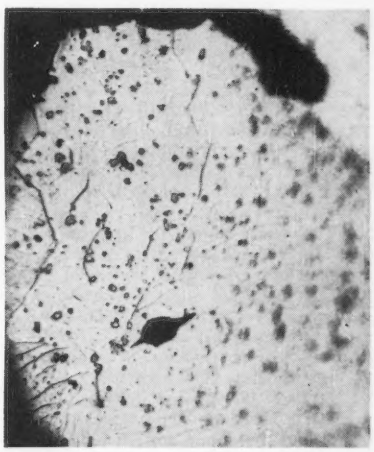


Figure 17D—Type 446 (27 percent Cr), annealed 1400 F, 4 hours AC. Specimen was metallographically polished, plastically stressed as bent beam sample and exposed in boiling $MgCl_2$ for 3 hours. Etchant, mixed acids; magnification, approximately 375X.

Stress corrosion cracking is apparently highly dependent on crystal orientation. This is demonstrated by Figure 17c which represents Type 304 after five minute exposure. Previous work on large grain 18Cr-12Ni steels[12] suggested that cracking occurs on the (111) planes oriented to give the lowest resolved shear stress for plastic deformation. This was also true on single crystals of alpha brass cracked in an ammonia atmosphere. It seems reasonable that the appearance of stress corrosion cracks normal to the applied stress in crystals which do not have (111) traces in this direction, are composed of short step-like cracks in this glide plane to produce the observed composite macro crack.

The literature is profuse with references indicating that ferritic stainless steels are not subject to chloride stress corrosion cracking.

To determine what happens when a ferritic steel such as Type 446 (27 per-

TABLE 7—Mechanical Properties of Alloys Studied for Individual Element Effect

Heat No.	Significant Element	Notched Tens. Str., psi	Ult. Tens. Str., psi	0.2% Yld. Str., psi	Elon. 4 x D, Percent	Red. Area, Percent
R-1740	Control Heat	87,200	75,500	35,600	60.0	72.0
R-1821	.016 C	82,500	71,000	30,800	62.0	76.0
R-1746	.15 N	100,500	76,000	32,500	62.0	75.3
R-1820	.11 C	91,200	75,700	34,400	62.0	72.8
R-1748	.005 C	79,800	70,600	32,100	40.0	73.5
R-1735	8.11 Ni	127,700	100,200	34,700	50.0	63.5
R-1737	16.04 Ni	83,700	73,500	33,600	52.0	76.4
R-1738	20.07 Ni	81,200	74,000	31,600	52.0	72.5
R-1739	30.13 Ni	.....	78,500	33,400	60.0	65.8
R-2290	49.92 Ni	.....	84,600	29,400	46.0	73.5
R-1742	7.93 Cr	170,200	149,000	130,000	18.0	56.5
R-1743	11.44 Cr	108,600	86,500	32,300	44.0	68.0
R-1744	15.64 Cr	84,700	73,500	35,000	62.0	74.0
R-1745	23.00 Cr	95,000	87,250	45,700	52.0	75.2
R-1732	0.10 Mn	88,200	75,000	36,500	55.0	73.0
R-1733	1.69 Mn	88,100	75,500	34,500	60.0	76.2
R-1747	0.22 Si	85,200	83,600	43,800	58.0	72.5
R-1710	0.92 Si	90,200	73,500	33,400	60.0	72.8
R-1707	1.89 Si	85,300	90,500	71,500	62.0	73.7
R-2341	2.14 Si	.....	.....	.....	.....	.....
R-1705	4.04 Si	113,200	99,000	61,500	62.0	74.0

cent Cr) is exposed to boiling magnesium chloride, annealed samples of this grade were plastically deformed and immersed in the boiling salt for three hours. It was noticed that pits similar to Types 304 and 310 were formed with what appeared to be cracks extending from them, but they did not grow with continued exposure. A typical pit and crack is shown in Figure 17d. To confirm the fact that ferritic stainless steels are not subject to stress corrosion cracking in chloride environments, a tensile type test was conducted at 70,000 psi for 1576 hours. The solution phase portion was still fairly bright and the vapor portion only lightly etched. No cracks were found.

Discussion of Results

It may be argued that stress corrosion tests that employ both solution and vapor phases do not accurately measure a material's resistance to stress corrosion cracking. This is probably true because there is undoubtedly a concentration of chlorides in long time vapor phase tests that constitute a variable which is not controlled. On the other hand, it would be misleading to conduct only total immersion tests. From such a test many alloys of the austenitic stainless steel type can be devised which would not appear susceptible but which might fail in service from conditions far different than from where there is a constant concentration of the corrosive media.

This was borne out by tilting autoclave tests in which the chloride solution concentration was considerably lower than that in the boiling 42 percent magnesium chloride solution. Samples failed in the vapor phase in relatively short times, yet appeared immune in fully immersed magnesium chloride.

The factors which govern whether a sample fails in the solution phase or in the vapor phase are not clear. At first glance, it appears to be primarily a function of time, but this is not the case for each of the steels considered. Type 304 failed in the solution phase at high stresses and short times but reverted to vapor phase failures after several hours. Type 310 failed consistently in the vapor phase, whereas Types 309 and 316 cracked in the solution in time periods that Type 304 normally showed predominantly vapor breaks. Worthite cracked in both solution and vapor phases in longer periods of time than Type 310. Possibly the selection of environment for cracking is determined solely by the alloy's inherent resistance to chloride attack and the degree of concentration of this corrodent.

Hoar and Hines[13] have suggested that the form of the results for stress vs. time to fracture can be represented by two intersecting straight lines. Those authors presented their data in semi-logarithmic manner silimar to that in the present paper. Apparently this cannot apply in all cases, as the data for Type 304-L and Type 347 in Figure 5 show. For these test results it was impossible to draw anything but curved lines to connect the fracture points. The "knee" of the curve, according to Hoar and Hines, is changed by mechanical working or heat treatment. The data contained in this paper generally support this statement. There is a tendency for aging or precipitation type treatments to alter the slope of the stress vs. time to failure curve and there appears to be a hint of dependency on the work hardening characteristics of the alloy tested. Generally, as the work hardening propensity decreased, the "knee" of the curve occurred at higher applied stresses. This is shown by the results of tests on nickel variations in Figure 12 in which the reduced work hardening is attributed to increased nickel. Table 7 shows lower ratios of notched to unnotched tensile values associated with higher nickel contents.

The results of the tests contained in this paper favor a combination of electrochemical and mechanical processes for causing stress corrosion cracking of austenitic stainless steels.

Not reported were tests in which specimens of 18-8 were cathodically charged externally and cracking was arrested; making the sample the anode with a low applied current density accelerated cracking. Similar experiments performed by coupling the specimen externally to electrodes of dissimilar metals in the solution proved the electrochemical nature of stress corrosion cracking. Aluminum and iron offered protection, whereas platinum, tantalum and nickel either accelerated or caused normal time failures. Similar findings have been reported by Logan[6], Hoar and Hines[14] and hosts of others.

The fact that chemical attack occurs preferentially in areas of deformed metal or work-hardened regions is generally accepted. It is not difficult to perceive of corrosion occurring, resulting in pits, in suitably oriented grains under applied or residual stresses. In fact, the very nature of the specimen used in this investigation would promote to an even greater extent this form of chemical activity. The multiaxial stresses imposed by the circumferential grooves would be expected to favor cross slip, resulting in many sites for the nucleation of chemical attack.[15] It may be reasoned that this combination of work hardening and attendant corrosive activity is, in part, responsible for the relative susceptibility of the commercial stainless steels. The lower the work hardening rate, the fewer sites for chemical activity and greater immunity to cracking. Furthermore, the fact that stress corrosion cracking does not occur in pure elements that have a FCC structure, such as copper, silver and aluminum, yet are capable of work hardening, suggests that attack proceeds on localized paths only in chemically non-homogenous alloys.

Unfortunately, it is not likely that stress corrosion cracking is as simple as theorized above. Other factors certainly have a bearing. For example, the effect of silicon cannot be ignored.

This strong ferrite former did not result in a secondary phase in the austenitic matrices tested. It did, however, increase the elastic properties with increasing amounts added. The work hardening rate apparently was only moderately affected. In addition to this is the probable effect this element has on the structure of the oxide film. Possibly the strengthening effect of silicon in solid solution could account for its beneficial effect. If so, it would be hard to explain why Armco 17-10 P exhibited little difference in stress corrosion resistance, whether hardened by aging or softened by solution treatment.

Logan's hypothesis[6] that micro creep takes place under low applied or residual stresses and results in cracks in the oxide film which exposes anodic areas that develop into cracks, is interesting. Studies in the author's own laboratories have indicated that appreciable creep does take place in 18-8 at both 300 F and room temperature (in the order of .002 percent per hour from 500 to 1000 hours at 80 F with 40,000 psi) and it seems likely that this could cause discontinuities in the oxide film. This proposal would appear strengthened in view of the favorable effect oxide coating treatments were found to have on the fracture time of annealed 18-8. On the other hand, the wide variation in yield strength of Armco 17-10 P in its aged and solution-treated conditions which would be expected to

greatly alter its low temperature creep rates does not reflect this property in resistance to stress corrosion cracking.

The probability that the forces of the corrosion products cause stress corrosion cracks, as advanced by Nielsen,[11] does not seem reconcilable with this investigation. It would be expected that ferritic alloys, such as Type 430 (17Cr) and Type 446 (27Cr) that are notably notch sensitive, would be susceptible to this process. The fact that Type 446 initiated pits with small cracks, similar to the austenitic alloys, but which did not extend or develop into longer cracks, opens question to the correctness of this hypothesis.

Conclusions

A test has been developed that produces accelerated and fairly reproducible results for establishing the boiling magnesium chloride stress corrosion resistance of austenitic stainless steels.

Commercial alloys tested under these conditions indicate that, where stress corrosion cracking is a factor to be considered in their use, attention should be given primarily to the nickel content of the alloy selected. Types 310 and 314 stainless steels offer considerably greater resistance to this type of attack than do the more commonly used Types 304, 316 and 347. It is possible that in borderline field applications the use of the more highly alloyed grades would result in satisfactory performance by virtue of their apparently higher threshold stress required to cause cracking.

No heat treatment was found to effectively alter the stress corrosion resistance of the commercial stainless steels, nor did varying surface conditions affect their performance under these test conditions, at least to an extent which would offer hope that alloys such as 18-8 could be protected against this form of attack.

Nickel and silicon apparently have the most pronounced effect on inhibiting stress corrosion cracking, whereas carbon, nitrogen, manganese and chromium exert only a minor influence.

Stress corrosion cracking of austenitic stainless steels appears to be of combined electrochemical and mechanical origin. The data suggest that the threshold stress required for cracking and the over-all resistance to cracking are in some way related to the deformation characteristics of the alloy, and, to a lesser extent, its protective oxide film.

Acknowledgments

The author expresses his thanks to his many associates who assisted in the work described in this paper. Special recognition is due J. F. Kreml who was directly responsible for carrying out the testing program. The author is indebted to G. C. Pierpont and R. H. Mackenzie for the metallographic test procedures and examinations, and to H. W. Garvin and M. Clogg who so patiently prepared the charts and photographic work. Finally he wishes to thank F. K. Bloom, Manager, Baltimore Research Laboratories, for his guidance throughout the investigation, and T. F. Olt, Vice President—Research, for permission to publish this paper.

References

1. M. A. Scheil. Symposium on Stress Corrosion Cracking of Metals, ASTM-AIME, 395-410 (1944).
2. H. Nathorst. An Investigation of the Suitability of the U-Bend Specimen. Welding Research Council, Bul. No. 6, 18 p. (1950).
3. Heinz Neuber. Theory of Notch Stresses: Principles for Exact Stress Calculation. J. Springer, Berlin, 1937; English ed.: Edwards Co., Ann Arbor, Mich. (trans. by F. A. Raven).
4. R. W. Staehle et al. *Corrosion*, 15, 373-381t (1959).
5. H. H. Uhlig and R. A. White. Some Metallurgical Factors Affecting Stress-Corrosion Cracking of Austenitic Stainless Steels. ASM Preprint No. 167 (1959). To be published in *Transactions*, ASM, 52 (1960).
6. H. L. Logan. Studies of Stress Corrosion Cracking of Austenitic Stainless Steels. *Welding Journal*, 37, No. 10, 463-467s (1958).
7. Charles F. Lewis. Statistics—A Useful Tool for the Examination of Corrosion Data. *Corrosion*, 9, 38-43 (1953).
8. H. R. Copson. Effect of Composition on Stress Corrosion Cracking of Some Alloys Containing Nickel. Preprint, AIME Conference (1959).
9. Anonymous. A Note on the Influence of Nitrogen in Steel. British Intelligence Objectives Sub-Committee, Report 898, 6 pp. (about 1946).
10. K. W. Leu and J. M. Helle. On the Mechanism of Stress Corrosion of Austenitic Stainless Steels in Hot Aqueous Chloride Solutions. *Corrosion*, 14, No. 5, 249-254t (1958).
11. N. A. Nielsen. The Role of Corrosion Product in Stress Corrosion Cracking of Austenitic Stainless Steels. Preprint, AIME Conference (1959).
12. E. E. Denhard. The Relationship Between Stress Corrosion Cracks and Crystallographic Orientation in Face Centered Cubic Metals. Thesis for Master's Degree, Johns Hopkins Univ. (1957).
13. T. P. Hoar and J. G. Hines: Stress Corrosion Cracking of Austenitic Stainless Steels in Aqueous Chloride Solutions. Stress Corrosion Cracking and Embrittlement. Edited by D. W. Robertson, J. Wiley & Sons, New York 1956, 107-25.
14. T. P. Hoar and J. G. Hines. Stress Corrosion Cracking of Austenitic Stainless Steels with Applied EMF. *Journal of Applied Chemistry*, 8, 764-776 (1958).
15. W. D. Robertson and R. Bakish: "Structural Factors Associated with the Stress Corrosion Cracking of Homogeneous Alloys." Stress Corrosion Cracking and Embrittlement. Edited by D. W. Robertson, J. Wiley & Sons, New York, 1956, 32-47.

Any discussion of this article not published above will appear in December, 1960 issue.

Directory of NACE Technical Committee Officers

T 1 Corrosion in Oil and Gas Well Equipment

W. C. Koger, Chairman; Cities Service Oil Co., Cities Service Bldg., Bartlesville, Oklahoma

J. A. Caldwell, Vice Chairman; Humble Oil & Refining Co., Box 2180, Houston, Texas

T-1A Corrosion in Oil and Gas Well Equipment, Los Angeles Area

R. L. Davis, Chairman; Superior Oil Co., 900 Palm Ave., South Pasadena, Cal.

T-1B Corrosion in Oil and Gas Well Equipment, Calgary Area

T-1C Detection of Corrosion in Oil Field Equipment

J. P. Barrett, Chairman; Pan American Petroleum Corp., Box 591, Tulsa, Okla.

F. A. Prange, Vice Chairman; Phillips Petroleum Corp., Bartlesville, Okla.

T-1D Control of Oil Field Corrosion by Chemical Treatment

C. C. Nathan, Chairman; Texaco, Inc., Box 425, Bellaire, Texas

J. R. Bruce, Vice Chairman; Shell Oil Co., 1700 S. Broadway, Denver, Colo.

T-1E Cathodic Protection of Oil Field Equipment

Jack L. Battle, Chairman; Humble Oil & Refining Co., Humble Div., Box 2180, Houston, Texas

J. E. Landers, Vice Chairman; Continental Oil Co., Drawer 1267, Ponca City, Okla.

T-1F Metallurgy of Oil Field Equipment

R. L. McGlasson, Chairman; Continental Oil Co., Res. & Dev. Lab., Box 1267, Ponca City, Okla.

T. M. Krebs, Vice Chairman; Babcock & Wilcox Co., Tubular Products Div., 1920 Seventh Ave., Beaver Falls, Pa.

R. S. Ladley, Secretary; Phillips Petroleum Co., Bartlesville, Okla.

T-1G Protective Coatings and Non-Metallic Materials for Oil Field Use

D. R. Fincher, Chairman; Tidewater Oil Co., 1538 Campbell Road, Houston 24, Texas

G. R. Roberson, Vice Chairman, Standard Oil Co. of Texas, Box 1249, Houston, Texas

T-1H Economics of Corrosion Control

R. M. Robinson, Chairman; Continental Oil Co., Box 2197, Houston, Texas

E. J. Simmons, Vice Chairman; Sun Oil Co., Box 2880, Dallas, Texas

T 2 Pipe Line Corrosion

W. H. Stewart, Chairman; Sun Pipe Line Co., P. O. Box 5292, Beaumont, Texas

Richard J. Emerson, Vice Chairman; El Paso Natural Gas Co., P. O. Box 1492, El Paso, Texas

T-2A Galvanic Anodes

M. A. Riordan, Chairman; Rio Engineering Co., Box 6035, Houston, Texas

R. L. Horst, Jr., Vice Chairman; Aluminum Co. of America, Box 1012, New Kensington, Pa.

T-2A-2 Development of Standard Accelerated Galvanic Anode Test Procedures

T-2B Anodes for Impressed Currents

Richard J. Emerson, Chairman; El Paso Natural Gas Co., P. O. Box 1492, El Paso, Texas

J. S. Dorsey, Vice Chairman; Southern California Gas Co., Box 3249, Terminal Annex, Los Angeles 54, Cal.

L. A. Hugo, Secretary; Engineering Department, Phillips Petroleum Co., Bartlesville, Okla.

T-2B-1 Sources of Impressed Current for Anodes

H. E. James, Chairman; Mississippi Valley Gas Co., Box 2447, W. Jackson Sta., Jackson 7, Miss.

T-2B-2 Ground Bed Design Data

F. I. Dorr, Chairman; 11838 Longleaf Lane, Houston 24, Texas

T-2B-4 Use of High Silicon Cast Iron for Anodes

W. A. Luce, Secretary; Duriron Co., Inc., Box 1019, Dayton 1, Ohio

T-2B-6 Deep Anodes

A. W. Peabody, Chairman; Ebasco Services, Inc., 2 Rector St., New York, N. Y.

T-2B-7 Use of Lead and Lead Alloys as Anodes

E. J. Mullarkey, Chairman; Lead Industries Ass'n, 292 Madison Ave., New York 17, N. Y.

T-2B-8 Anode Lead Wires

T. J. Maitland, Chairman; American Tel. & Tel. Co., 32 Avenue of the Americas, New York 13, N. Y.

T-2C Criteria for Cathodic Protection

L. C. Wasson, Chairman; A. O. Smith Corp., 3533 N. 27th St., Milwaukee, Wis.

A. W. Peabody, Vice Chairman; Ebasco Services, Inc., 2 Rector St., New York, N. Y.

T-2C-1 Basic Criteria

K. G. Compton, Chairman; Bell Telephone Labs., Murray Hill, N. J.

T-2C-2 Coupons, As A Criteria for Cathodic Protection

H. J. Keeling, Chairman; Consulting Engineer, 1780 E. Robertson Blvd., Los Angeles 35, Cal.

T-2C-3 History

T-2C-4 Cathodic Protection Criteria Research

L. P. Sudrabin, Chairman; Electro Rust-Proofing Corp., P. O. Box 178, Newark 1, New Jersey

T-2D Standardization of Procedures for Measuring Pipe Coating Leakage Conductance

L. F. Heverly, Chairman; Trans-Canada Pipe Lines Ltd., 150 Eglinton Ave. E, Toronto 12, Ontario, Canada

E. R. Allen, Jr., Vice Chairman; Humble Pipe Line Co., Engineering Lab, Rt. 7, Box 1400, Houston, Texas

T-2D-1 Short Insulated Sections of Low Conductance

Marshall E. Parker, Chairman; 2023 Jean, Houston 23, Texas

T-2D-2 Inaccessible Locations, Such as Water Crossings

H. V. Beezley, Chairman; United Gas Pipe Line Co., Box 1407, Shreveport, La.

TECHNICAL PRACTICES COMMITTEE

T. J. Maitland, Chairman; American Tel. & Tel. Co., 32 Avenue of the Americas, New York 13, New York

Jack L. Battle, Vice Chairman; Humble Oil & Refining Co., P. O. Box 2180, Houston, Texas

E. C. Greco, United Gas Corp., P. O. Box 1407, Shreveport, La.

Chairmen of T-1 through T-9 also are members of this committee.

T-2D-3 Parallel Lines

L. A. Hugo, Chairman; Phillips Petroleum Co., Bartlesville, Okla.

T-2D-5 Pipe Observed to Be in a Stray Current Field

T-2E Internal Corrosion of Product Pipe Lines and Tanks

Ivy M. Parker, Chairman; Plantation Pipe Line Co., Box 1743, Atlanta, Ga.

A. W. Jasek, Vice Chairman; Humble Pipe Line Co., Drawer 2220, Houston 1, Texas

T-2F Internal Corrosion of Crude Oil Pipe Lines and Tanks

E. R. Allen, Temporary Chairman; Humble Pipe Line Co., Eng. Lab., Rt. 7, Box 1400, Houston, Texas

T-2G Coal Tar Coatings for Underground Use

T. F. P. Kelly, Chairman; Mavor-Kelly Co., 660 M & M Building, Houston 2, Texas

W. F. Fair, Jr., Vice Chairman; Koppers Co., Inc., Tar Products Div., Tech. Sec., 15 Plum St., Verona, Pa.

T-2H Asphalt Type Pipe Coatings

Frank B. Burns, Chairman; General Asphalts, Inc., Sub. of Kerr-McGee Oil Industries, Inc., P. O. Box 305, Wynnewood, Okla.

Wayne E. Broyles, Vice Chairman; Brance-Krachy Co., Inc., P. O. Box 1724, Houston 1, Texas

T-2H-2 Criteria to Be Used in Reporting on and Evaluating the Performance of Asphalt-Type Pipe Coatings

C. E. Lee, Chairman; Southern California Gas Co., Box 3249, Terminal Annex, Los Angeles 54, Cal.

T-2H-3 To Assemble and Present Service Histories of Asphalt-Type Pipe Coatings

John L. Rohwedder, Chairman; U. S. Corps of Engineers, Clock Tower Bldg., Rock Island, Ill.

T-2H-4 Asphalt-Type Internal Coating for Pipe Lines

F. B. Burns, Chairman; General Asphalts, Inc., Kerr-McGee Oil Industries, Inc., Box 305, Wynnewood, Okla.

T-2H-5 To Review and Encourage Publication of Technical Articles on Asphalt-Type Protective Coatings

L. S. Parker, Chairman; Fibreboard Paper Products Corp., 475 Brannan St., San Francisco 19, Cal.

T-2H-6 Asphalt Testing Technics on a Non-Technical Level

Lloyd F. Bramble, Chairman; Gulf States Asphalt Co., Inc., 1522 Melrose Bldg., Houston 2, Texas

T-2J Wrappers for Underground Pipe Line Coating

R. A. Brannon, Chairman; Humble Pipe Line Co., P. O. Box 2220, Houston 1, Texas

L. B. Nelson, Vice Chairman; Shell Pipe Line Co., P. O. Box 2648, Houston, Texas

T-2J-1 Asbestos Felt

T-2J-2 Glass Wrap

T-2J-3 Glass Base Outer Wrap

F. B. Burns, Chairman; General Asphalts, Inc., Kerr-McGee Oil Industries, Inc., Box 305, Wynnewood, Okla.

T-2J-4 Rag Felt

L. S. Parker, Chairman; Fibreboard Paper Products Corp., 475 Brannan St., San Francisco 19, Cal.

T-2J-5 Rock Shield

Henry B. Hutten, Chairman; The Ruberoid Co., 500 5th Avenue, New York 36, New York

T-2K Prefabricated Plastic Film for Pipe Line Coating

J. J. Wise, Chairman; Arkansas-Louisiana Gas Co., Box 1734, Shreveport, La.

H. D. Segool, Vice Chairman; The Kendall Co., Polyken Sales Division, 309 West Jackson Blvd., Chicago 6, Ill.

T-2K-1 Standards

H. D. Segool, Chairman; Kendall Co., Polyken Sales Div., 309 W. Jackson Blvd., Chicago 6, Ill.

T-2K-2 Research and Development

Mel A. Henrickson, Chairman; Minnesota Mining & Mfg. Co., 900 Bush Ave., St. Paul, Minn.

T-2K-3 History and Results

F. E. Costanzo, Chairman; Manufacturers Light & Heat Co., 253 Ryan Drive, Pittsburgh 19, Pa.

T-2L Wax-Type Pipe Coatings and Component Wrappers

J. O. Mandley, Chairman; Michigan Consolidated Gas Co., 415 Clifford, Detroit 26, Mich.

I. E. Davis, Vice Chairman; 4405 Marland Dr., Columbus 24, Ohio

T-2M Aluminum Pipeline Corrosion

H. P. Godard, Chairman; Aluminium Lab. Ltd., P. O. Box 8400, Kingston, Ontario, Canada

R. S. Dalrymple, Vice Chairman; Reynolds Metals Co., Box 2346, Richmond 18, Va.

Charles F. Warnock, Secretary; Apartado 234, Maracaibo, Venezuela, S. A.

T-2M-1 Corrosion Behavior of Aluminum in Soil

H. L. Craig, Jr., Chairman; Reynolds Metals Co., Metallurgical Res. Labs., 4th & Canal Streets, Richmond 19, Va.

T-2M-2 Cathodic Protection of Aluminum

F. W. Hewes, Chairman; Canadian Protective Coating Ltd., 9420 91st St., Edmonton, Alberta, Canada

T-2M-3 Coating and Wrapping Aluminum

M. A. Riordan, Chairman; Rio Engineering Co., Box 6035, Houston, Texas

T-2M-4 Corrosion of Submarine Aluminum Pipe Lines in Lake Maracaibo, Venezuela

Charles F. Warnock, Chairman; Apartado 234, Maracaibo, Venezuela, S. A.

T-2M-5 Corrosion of Submarine Aluminum Pipelines in Sea Water

E. T. Wanderer, Chairman; Aluminum Co. of America, P. O. Box 1012, New Kensington, Pa.

T-2M-6 Corrosion of Submarine Aluminum Pipelines in Fresh Water

H. D. Walford, Chairman, Aluminum Co. of Canada, Ltd., Box 6090, Montreal 3, Quebec, Canada

T-2M-7 Internal Corrosion Problems for Handling Oilfield Brines, Crude Oil, and Natural Gases

Joseph U. Messenger, Chairman; Mobil Oil of Canada, Ltd., Mobil Oil Bldg., Calgary, Alberta, Canada

T 3 General

D. A. Vaughan, Chairman; Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio

L. C. Rowe, Vice Chairman; Research Labs., General Motors Corp., 12 Mile & Mound Roads, Warren, Mich.

T-3A Corrosion Inhibitors

L. C. Rowe, Chairman; Research Labs., General Motors Corp., 12 Mile & Mound Roads, Warren, Mich.

A. J. Freedman, Vice Chairman; Nalco Chemical Co., 6216 West 66th Place, Chicago 38, Ill.

T-3A-2 Methods of Testing & Screening Corrosion Inhibitors

(Chairman to be Selected)

T-3A-3 Materials Available for and Application of Corrosion Inhibitors

Directory of NACE Technical Committee Officers

L. A. Timm, Chairman; Saran Lined Pipe Co., 6 W. Broad St., Room 410, Bethlehem, Pa.

T-3B Corrosion Products

A. H. Roebuck, Chairman; Western Company, Fort Worth Club Bldg., P. O. Box 186, Fort Worth 1, Texas

D. A. Vaughan, Vice Chairman; Battelle Memorial Institute, 505 King Avenue, Columbus Ohio

T-3C Annual Losses Due to Corrosion

S. K. Coburn, Chairman; Applied Research Lab., United States Steel Corp., Monroeville, Pa.

T-3D Instruments for Measuring Corrosion

E. H. Thalmann, Chairman; Ebasco Services, Inc., 2 Rector St., New York, N. Y.

F. W. Ringer, Vice Chairman; 7 Hampden Ave., Narberth, Pa.

T-3D-1 Electrical Holiday Inspection of Coatings

W. A. Broome, Chairman; Arkansas-Louisiana Gas Co., Box 1734, Shreveport 4, La.

T-3E Railroads

L. J. Nicholas, Chairman; Pullman Co., 165 N. Canal St., Chicago 6, Ill.

G. M. Magee, Vice Chairman; Assoc. American Railroads, 3140 South Federal Street, Chicago, Ill.

T-3E-1 Corrosion of Railroad Tank Cars

C. M. Jekot, Vice Chairman; DeSoto Paint & Varnish Co., P. O. Box 186, Garland, Texas

T-3E-2 Corrosion in Railroad Hopper Cars

C. L. Crockett, Chairman; Norfolk and Western Railway, Motive Power Dept., Roanoke, Va.

T-3F Corrosion by High Purity Water

R. U. Blaser, Chairman; Research Center, Babcock & Wilcox Co., Box 835, Alliance, Ohio

M. C. Bloom, Vice Chairman; Metallurgy Div., Naval Research Lab., Washington 20, D. C.

T-3F-2 Inhibitors

R. C. Ulmer, Chairman; Combustion Engineering Co., 200 Madison Avenue, New York, N. Y.

T-3F-3 Corrosion Products

W. L. Pearl, Chairman; General Electric Company, Atomic Power Equipment Dept., Box 254, San Jose, Cal.

T-3F-6 Intercommittee Activities

E. P. Partridge, Chairman; Hall Labs., Inc., Box 1346, Pittsburgh, Pa.

T-3F-7 Bibliography

W. K. Boyd, Chairman; Battelle Memorial Institute, 505 King Ave., Columbus, Ohio

T-3G Cathodic Protection

Dr. T. P. May, International Nickel Co., Inc., P. O. Box 262, Wrightsville Beach, North Carolina

J. L. Miller, Secretary; National Carbon Co., Div. of Union Carbide Co., Box 6087, Cleveland 1, Ohio

T-3G-1 Cathodic Protection of Hull Bottoms of Ships

L. P. Sudrabin, Chairman; Electro Rust-proofing Corp., Box 178, Newark, New Jersey

H. S. Preiser, Vice Chairman; 6904 Leesville Blvd., North Springfield, Va.

T-3G-2 Cathodic Protection of Heat Exchangers

R. B. Teel, Chairman; International Nickel Co., Inc., 333 N. Michigan Ave., Chicago 1, Ill.

T-3G-3 Cathodic Protection of Process Equipment

A. A. Brouwer, Chairman; The Dow Chemical Co., 52 Bldg., Midland, Michigan

T-3H Tanker Corrosion

W. S. Quimby, Chairman; Res. & Tech. Dept., Texaco, Inc., Box 509, Beacon, New York

T4 Utilities

J. B. Prime, Jr., Chairman; Florida Power & Light Co., Box 3100, Miami 30, Fla.

A. L. Ayres, Vice Chairman; New Jersey Bell Tel. Co., 540 Broad St., Rm. 1600, Newark 2, N. J.

T-4A Effects of Electrical Grounding on Corrosion

O. W. Zastrow, Chairman; Electric Engineering Div., Rural Electrification Adm., USDA, Washington 25, D. C.

C. L. Mercer, Vice Chairman; Southwestern Bell Tel. Co., Box 58, Westfield, Texas

T-4A-3 Methods and Materials for Grounding

I. C. Dietze, Chairman; Dept. of Water & Power, Box 3669, Terminal Annex, Los Angeles 54, Cal.

T-4A-4 Coordination of Utility Grounding Practices

A. F. Minor, Chairman; American Tel. & Tel. Co., 195 Broadway, New York 7, N. Y.

T-4B Corrosion of Lead and Other Metallic Cable Sheaths

H. M. Clayton, Vice Chairman; Memphis Gas, Light and Water Div., Box 388, Memphis, Tenn.

T-4C Non-Metallic Sheaths and Coatings

T-4C-1 Practices and Experience with Protective Jackets for Outside Plant Lead and Aluminum Sheathed Power Cables

L. O. McCormick, Chairman; Baltimore Gas & Electric Co., Madison Street Building, Baltimore 3, Md.

T-4C-2 Communication Cables with Corrosion Resistant Covering or Coating

A. F. Minor, Chairman; American Tel. & Tel. Co., 195 Broadway, New York 7, N. Y.

T-4D Corrosion by Deicing Salts

K. G. Compton, Chairman; Bell Telephone Laboratories, Murray Hill, New Jersey

L. C. Rowe, Vice Chairman; Research Labs., General Motors Corp., 12 Mile & Mound Roads, Warren, Mich.

T-4D-1 Procedures for Conducting Field Tests Below Ground

F. E. Kulman, Chairman. Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York, N. Y.

T-4D-2 Coordination of Field Programs Between Cities and Transportation Companies

George Illig, Chairman; Calgon, Inc., 323 Fourth Ave., Pittsburgh, Penn.

T-4E Corrosion by Domestic Waters

J. F. J. Thomas, Chairman; Industrial Waters Section, Dept. of Mines & Technical Surveys, 40 Lydia Street, Ottawa, Ontario, Canada

R. W. Lane, Vice Chairman; Illinois State Water Survey, Water Resources Bldg., 605 E. Springfield, Champaign, Ill.

T-4E-1 Hot Water Tank Corrosion

H. C. Fischer, Chairman; Thermo Craft Corp., Montville, N. J.

T-4F Materials Selection for Corrosion Mitigation in the Utility Industry

W. T. Burgess, Chairman; Metropolitan Utilities District, 18th & Harney Street, Omaha 2, Nebraska

I. C. Dietze, Vice Chairman; Dept. of Water & Power, Box 3669, Terminal Annex, Los Angeles 54, California

T-4F-1 Materials Selection in the Water Industry

Daniel Cushing, Chairman; 148 State St., Boston, Massachusetts

Chester Anderson, Vice Chairman; The Crane Co., 836 South Michigan Avenue, Chicago 5, Ill.

Peter Kahn, Secretary; Metcalf & Eddy, 1300 Statler Bldg., Boston, Mass.

T-4F-2 Materials Selection in the Electric Industry

F. E. Kulman, Chairman; Consolidated Edison Co. of New York, Inc., 4 Irving Place, New York 3, N. Y.

T-4G Protection of Pipe Type Cables

F. E. Kulman, Chairman; Consolidated Edison Co. of N. Y., Inc., 4 Irving Place, New York 3, N. Y.

R. C. Jacobsen, Vice Chairman; Hydro-Electric Power Commission of Canada, 32 Lowther, Toronto, Ontario, Canada

T-4G-1 General Coating Study

F. E. Kulman, Chairman; Consolidated Edison Co. of N. Y., Inc., 4 Irving Place, New York 3, N. Y.

T-4H Tests and Surveys of Cable Sheaths

H. W. Dieck, Chairman; Long Island Lighting Co., 175 Old Country Road, Hicksville, N. Y.

R. W. Ackermann, Vice Chairman; American Tel. & Tel. Co., 1014 Vine Street, Cincinnati 2, Ohio

T-4J Cathodic Protection of Cable Sheaths

Harry E. Kroon, Chairman; 4956 Dobson St., Skokie, Ill.

Roy O. Dean, Vice Chairman; Pacific Gas and Electric Co., 4245 Hollis St., Emeryville 8, Cal.

T-4J-1 Interference from Cathodic Protection Rectifiers

C. L. Mercer, Chairman; Southwestern Bell Tel. Co., P. O. Box 58, Westfield, Texas

T5 Corrosion Problems in the Process Industries

C. P. Dillon, Chairman; Union Carbide Chemicals Co., Div. of Union Carbide Corp., P. O. Box 2831, Charleston, W. Virginia

W. H. Burton, Vice Chairman; General Chemical Div., Allied Chemical Corp., 1100 Line St., Camden 3, N. J.

T-5A Corrosion in Chemical Processes

W. H. Burton, Chairman; General Chemical Div., Allied Chemical Corp., 1100 Line St., Camden 3, N. J.

Dr. L. W. Gleekman, Vice Chairman; Wyandotte Chemicals Corp., 1609 Biddle Ave., Wyandotte, Mich.

T-5A-1 Inorganic Acids and Derivatives

N. D. Groves, Chairman; Carpenter Steel Co., 101 West Bern St., Reading, Pa.

T-5A-2 Organic Acids and Derivatives

R. H. Scott, Chairman; Route 2, Box 2, Bishop, Texas

T-5A-3 Alkali Environment

George P. Gladis, Chairman; International Nickel Co., Inc., 67 Wall Street, New York 5, N. Y.

T-5B High Temperature Corrosion

David Roller, Chairman; Magna Products, Inc., 11808 South Bloomfield Ave., Santa Fe Springs, Cal.

D. W. McDowell, Jr., Vice Chairman; International Nickel Co., Inc., 67 Wall St., New York 5, N. Y.

T-5C Corrosion by Cooling Waters

T-5C-1 Corrosion by Cooling Waters (South Central Region)

J. M. Brooke, Chairman; Phillips Petroleum Co., Sweeny Refinery, Sweeny, Texas

A. S. Krisher, Vice Chairman; Monsanto Chemical Co., Plastics Div., Texas City, Texas

L. Miller Rogers, Secretary; Union Carbide Chemicals Co., P. O. Box 471, Texas City, Texas

T-5C-2 Corrosion by Cooling Waters (North Central Region)

William A. Hess, Chairman; Standard Oil Co. (Ohio), Midland Bldg., Cleveland 15, Ohio

D. B. Jones, Vice Chairman; Goodyear Atomic Corp., P. O. Box 628, Portsmouth, Ohio

J. R. Cross, Secretary; Standard Oil Co. (Ohio), Midland Bldg., Cleveland 15, Ohio

T-5D Plastic Materials of Construction

R. E. Gackenbach, Chairman; American Cyanamid Co., 30 Rockefeller Plaza, New York 20, N. Y.

Otto H. Fenner, Vice Chairman; Monsanto Chemical Co., 1700 South Second St., St. Louis 77, Mo.

T-5E Stress Corrosion Cracking of Austenitic Stainless Steel

E. V. Kunkel, Chairman; Celanese Corp. of America, P. O. Box 428, Bishop, Texas

H. R. Copson, Vice Chairman; 18 Hampton St., Cranford, N. J.

T6 Protective Coatings

O. H. Fenner, Chairman; Monsanto Chemical Co., 1700 South Second St., St. Louis 77, Mo.

R. H. Bacon, Vice Chairman; Dow Chemical Co., Maintenance Staff, Freeport, Texas

T-6A Organic Coatings and Linings for Resistance to Chemical Corrosion

L. S. Van Delinder, Chairman; Union Carbide Chemicals Co., Dev. Dept., South Charleston, W. Va.

V. B. Volkening, Vice Chairman; Dow Chemical Co., Route 1, Freeport, Texas

J. I. Richardson, Secretary; Amercoat Corp., 4809 Firestone Blvd., South Gate, Cal.

T-6A-1 Rubber Linings

R. McFarland, Jr., Chairman; Hills-McCanna Co., 400 Maple Street, Carpentersville, Illinois

T-6A-2 Vinyl Coatings

T-6A-3 Vinylidene Chloride Polymers

W. E. F. Rupprecht, Chairman; Dow Chemical Co., Coatings Technical Service, 433 Bldg., Midland, Mich.

T-6A-4 Phenolics

Forest Baskett, Chairman; Sheet Metal Engineers, Inc., Box 9384, Houston, 11, Texas

T-6A-5 Polyethylene

L. S. Van Delinder, Chairman; Carbide & Carbon Chemicals Co., South Charleston, W. Va.

T-6A-6 Neoprene

D. J. Kelly, Chairman; E. I. du Pont de Nemours & Co., Inc., Box 406, Wilmington, Del.

T-6A-7 Thermosetting Coal Tar Coatings

Woodrow E. Kemp, Chairman; Koppers Co., Inc., 15 Plum St., Verona, Pa.

T-6A-9 Furanes

T-6A-10 Polyesters

D. D. Cone, Chairman; 1806 Florida, Baytown, Texas

T-6A-11 Epoxys

C. G. Munger, Chairman; Amercoat Corp., 4809 Firestone Blvd., South Gate, Cal.

Directory of NACE Technical Committee Officers

T-6A-12 Fluorocarbons

Sylvan B. Falck, Chairman; Inner-Tank Lining Corp., 4777 Eastern Ave., Cincinnati 26, Ohio

T-6A-13 Chlorinated Rubbers

Appointment Pending

T-6A-14 Organic-Brick Covered

T-6A-15 Rigid Vinyls

C. G. Munger, Chairman; Amercoat Corp., 4809 Firestone Blvd., South Gate, Cal.

T-6A-16 Coal Tar Coatings

T-6A-17 Polyurethanes

E. R. Wells, Chairman; Mobay Chemical Co., Research Laboratories, New Martinsville, W. Va.

T-6A-18 Hypalon

D. J. Kelly, Chairman; E. I. du Pont de Nemours & Co., Inc., Box 406, Wilmington, Del.

T-6A-19 Asphalts

T-6A-20 Plastisols

Otto H. Fenner, Chairman; Monsanto Chemical Co., 1700 South Second St., St. Louis 77, Mo.

T-6A-21 Compile Reports for Binding Into One Volume

T-6B Protective Coatings for Resistance to Atmospheric Corrosion

Robert P. Suman, Chairman; Pittsburgh Plate Glass Co., P. O. Box 21114, Houston 26, Texas

M. W. Belue, Jr., Vice Chairman; Champion Paper & Fibre Co., P. O. Box 872, Pasadena, Texas

T-6B-1 Linseed and Other Drying Oils

John D. Keane, Chairman; Steel Structures Painting Council, 4400 5th Ave., Pittsburgh 13, Pa.

T-6B-2 Ester Gum Oil

R. L. Liston, Chairman; Cook Paint & Varnish Co., Box 3088, Houston, Texas

T-6B-3 Straight Phenolic Oil Varnish

John W. Nee, Chairman; Briner Paint Mfg. Co., 3713 Agnes St., Corpus Christi, Texas

T-6B-4 Modified Phenolic Oil Varnish

John W. Nee, Chairman; Briner Paint Mfg. Co., Inc., 3713 Agnes St., Corpus Christi, Texas

T-6B-5 Straight Alkyd Varnish

William F. Conners, Chairman; Humble Oil & Refining Co., Box 2180, Houston, Texas

Robert M. Ives, Jr., Vice Chairman; Sales Tech. Service Div., Humble Oil & Refining Co., P. O. Box 2180, Houston, Texas

T-6B-6 Modified Alkyd Varnish

Robert M. Ives, Jr., Chairman; Sales Tech. Service Div., Humble Oil & Refining Co., P. O. Box 2180, Houston, Texas

William F. Conners, Vice Chairman; Humble Oil & Refining Co., Box 2180, Houston, Texas

T-6B-7 Epoxy Esters

Howell C. Owens, Chairman; Coast Paint & Lacquer Co., Inc., P. O. Box 1113, Houston, Texas

John G. Raudsep, Vice Chairman; Shell Chemical Co., P. O. Box 2099, Houston 1, Texas

T-6B-8 Epoxy (Amine Cured)

John G. Raudsep, Chairman; Shell Chemical Co., P. O. Box 2099, Houston 1, Texas

Howell C. Owens, Vice Chairman; Coast Paint & Lacquer Co., Inc., P. O. Box 1113, Houston, Texas

T-6B-9 Chlorinated Rubber

Otto Grosz, Chairman; The California Co., Box 128, Harvey, La.

T-6B-10 Vinyls

John I. Richardson, Chairman; Amercoat Corporation, 4809 Firestone Blvd., South Gate, Cal.

T-6B-11 Zinc Filled Inorganic Coatings

F. Parker Helms, Chairman; Union Carbide Chemicals Co., P. O. Box 471, Texas City, Texas

T-6B-12 Coal Tar

T-6B-13 Asphalt

C. C. Allen, Chairman; Anderson-Prichard Oil Corp., 1000 Liberty Bank Bldg., Oklahoma City 2, Okla.

T-6B-14 New Developments

Joseph E. Rench, Chairman; Napko Corp., P. O. Box 14126 Houston 21, Texas

T-6B-15 Heat Resistant Silicones

W. F. Gross, Chairman; c/o Norton Jaggard, Manager Engineering, Arabian American Oil Co., 505 Park Ave., New York 22, N. Y.

T-6B-16 Polyurethanes

E. R. Wells, Chairman; Mobay Chemical Co., Coatings Res., Research Lab., New Martinsville, W. Va.

T-6B-17 Chemical Cured Coal Tar Coatings

R. H. Goodnight, Chairman; Cook Paint & Varnish Co., Box 389, North Kansas City, Mo.

T-6B-18 Zinc Coatings

J. W. Cushing Jr., Chairman; Carboline Co., #32 Hanley Industrial Court, St. Louis 17, Mo.

T-6C Protective Coatings for Resistance to Marine Corrosion

L. S. Van Delinder, Temporary Chairman, Union Carbide Chemicals Co., Development Dept., South Charleston, W. Va.

T-6D Industrial Maintenance Painting

F. Parker Helms, Chairman; Union Carbide Chemicals Co., P. O. Box 471, Texas City, Texas

D. D. Cone, Vice Chairman; 1806 Florida, Baytown, Texas

T-6D-1 Economics of Maintenance Painting

Stanley L. Lopata, Chairman; Carboline Company, #32 Hanley Industrial Center, St. Louis 17, Mo.

T-6D-2 Standardization of Scope of Painting Specifications

L. L. Sline, Chairman; Sline Industrial Painters, 2162 Gulf Terminal Dr., Houston, Texas

T-6D-4 Specifications for Shop Cleaning & Priming

L. L. Sline, Chairman; Sline Industrial Painters, 2162 Gulf Terminal Drive, Houston 23, Texas

T-6D-5 Painter Safety

Lowell Hartman, Chairman; Hartman-Walsh Painting Co., 5078 Easton St., St. Louis 13, Mo.

T-6D-6 Painter Education

C. W. Sisler, Chairman; John F. Queeny Plant, Monsanto Chemical Co., 1700 South Second St., St. Louis, Mo.

T-6E Protective Coatings in Petroleum Production

C. J. Fritts, Chairman; Socony Paint Products Co., Box 1740, Houston, Texas

F. E. Blount, Vice Chairman; Socony Mobil Labs., Box 900, Dallas 1, Texas

T-6F Protective Interior Linings, Application and Methods

W. P. Cathcart, Chairman; Tank Lining Corp., 246 Washington Road, Pittsburgh 16, Pa.

Bernard Saffian, Vice Chairman; Chamberlain Lab., U. S. Stoneware Co., Fishcreek Road, Box 624, Stow, Ohio

James Cogshall, Secretary; Pennsalt Chemical Corp., Corrosion Engr. Products Dept., Natrona, Pa.

T-6F-1 Curing

K. G. Lefevre, Chairman; Metalweld, Inc., 2617 Hunting Park Ave., Philadelphia 29, Pa.

T-6F-2 Surface Preparation

T-6F-3 Inspection

J. L. Barker, Jr., Chairman; Works Engineering Dept., Union Carbide Chemicals Co., Box 8004, Bldg. 82-821, S. Charleston 3, W. Va.

T-6F-4 Safety

J. L. Barker, Jr., Chairman; Works Engineering Dept., Union Carbide Chemicals Co., Box 8004, Bldg. 82-821, S. Charleston 3, W. Va.

T-6F-5 Application

T-6F-6 Ethics

T-6G Surface Preparation for Organic Coatings

Joseph Bigos, Chairman; U. S. Steel Corp., Monroeville, Pa.

John D. Keane, Vice Chairman; Steel Structures Painting Council, 4400 5th Ave., Pittsburgh 13, Pa.

T-6H Glass Linings and Vitreous Enamels

R. McFarland, Jr., Chairman; Hills-McCanna Co., 400 Maple St., Carpentersville, Ill.

D. K. Priest, Vice Chairman; Pfaudler Div., Pfaudler Permutit, Inc., 1000 West Avenue, Rochester 11, N. Y.

D. B. Johnson, Secretary; Glascote Products, Inc., 20900 St. Clair Ave., Cleveland 17, Ohio

T-6H-1 Glass Coatings

T-6H-2 Porcelain Enamel Coatings

A. R. Leyerle, Chairman; Vitreous Steel Products Co., P. O. Box 3991, Cleveland 20, Ohio

T-6J Protective Coating Application Problems

T-6J Los Angeles Area, Protective Coating Application Problems

Mrs. Flora L. Davis, Chairman; 22379 MacFarlane Dr., Woodland Hills, Cal.

Newell W. Tune, Secretary; L. A. Water & Power, 510 East 2nd St., Los Angeles, Cal.

T-6J-1 Specification Writing

Newell Tune, Chairman; L. A. Water & Power, 510 East Second St., Los Angeles, Cal.

T-6J-2 Application Procedure

David Jaffee, Chairman; Williams Waterproofing Co., 3107 Fletcher Dr., Los Angeles, Cal.

T-6J-3 Inspection Techniques

Mrs. Flora L. Davis, Chairman; 22379 MacFarlane Dr., Woodland Hills, Cal.

T-6J-4 Cost Evaluation

W. J. Frith, Chairman; Service Coating Corp., P. O. Box 524, Wilmington, Cal.

T-6R Protective Coatings Research

J. H. Cogshall, Chairman; Pennsalt Chemicals Corp., Corrosion Engineering Products Dept., Natrona, Pa.

T7 Corrosion Coordinating Committee

C. L. Mercer, Chairman; Southwestern Bell Tel. Co., P. O. Box 58, Westfield, Texas

Paul C. Hoy, Vice Chairman; Dayton Power & Light Co., 25 North Main St., Dayton, Ohio

T-7A Northeast Region Corrosion Coordinating Committee

C. A. Erickson, Chairman; Peoples Natural Gas Co., Two Gateway Center, Pittsburgh 22, Pa.

L. A. Kellogg, Vice Chairman, Niagara Mohawk Power Corp., 300 Erie Blvd. West, Syracuse, N. Y.

New Jersey Committee on Corrosion

R. J. Bishop, Chairman, Public Service Electric & Gas Co. of N. J., 80 Park Place, Newark, N. J.

C. W. Beggs, Vice Chairman; Public Service Electric & Gas Co., 80 Park Place, Newark, N. J.

E. T. Pearson, Secretary; Testing Lab., 200 Boyden Ave., Maplewood, N. J.

Greater New York Committee on Corrosion

W. E. Ripley, Chairman; New York Central Railroad, 466 Lexington Ave., New York, N. Y.

F. E. Kulman, Vice Chairman; Consolidated Edison Co. of N. Y., Inc., 4 Irving Place, New York 3, N. Y.

Western New York State Corrosion Committee

A. Fini, Chairman; Niagara Mohawk Power Corp., 93 Dewey Ave., Buffalo 14, N. Y.

R. M. Keller, Vice Chairman; Atlantic Pipeline Co., 5368 Magnolia, Philadelphia, Pa.

J. V. Adkin, Secretary; Rochester Gas & Electric Corp., 89 East Ave., Rochester 4, N. Y.

Southern W. Virginia Corrosion Coordinating Committee

K. R. Gosnell, Chairman; Development Dept., Union Carbide Chemicals Co., South Charleston, W. Va.

P. F. Sweeney, Vice Chairman; Chesapeake & Potomac Tel. Co. of W. Va., 816 Lee St., Charleston 5, W. Va.

James A. Parker, Secretary; United Fuel Gas Co., P. O. Box 1273, Charleston 25, W. Va.

Greater Boston Electrolysis Committee

William Helm, Jr., Chairman; Boston Gas Co., 100 Arlington St., Boston, Mass.

J. J. Molloy, Vice Chairman; Cambridge Electric Light Co., 46 Blackstone St., Cambridge, Mass.

Henry E. Wilkins, Secretary-Treasurer; Central Laboratory, New England Electric System, 939 Southbridge St., Worcester 10, Mass.

Western Pennsylvania Corrosion Committee

John B. Vrable, Chairman; New York State Natural Gas Corp., Two Gateway Center, Pittsburgh 22, Pa.

G. C. Picht, Jr., Vice Chairman; American Tel. & Tel. Co., 429 Fourth Ave., Pittsburgh 19, Pa.

F. E. Costanzo, Secretary; Manufacturers Light & Heat Co., 253 Ryan Drive, Pittsburgh 19, Pa.

Pittsburgh Corrosion Committee

C. M. Rutter, Chairman; Equitable Gas Co., 420 Blvd. of the Allies, Pittsburgh, Pa.

D. W. Kissinger, Vice Chairman; Duquesne Light Co., 1241 Reedsdale Street, Pittsburgh 33, Pa.

E. W. Steel, Secretary; Bell Telephone Co., of Pa., 201 Stanwix St., 3rd Floor, Pittsburgh 22, Pa.

T-7B North Central Region Corrosion Coordinating Committee

Paul C. Hoy, Chairman; Dayton Power & Light Co., 25 N. Main St., Dayton, Ohio

J. O. Mandley, Vice Chairman; Michigan Consolidated Gas Co., 415 Clifford, Detroit 26, Mich.

Chicago Region Committee on Underground Corrosion

C. N. Crowe, Chairman; Standard Oil Co. (Ind.), Box 5910-A, Chicago 80, Ill.

H. E. Kroon, Vice Chairman; 4956 Dobson St., Skokie, Ill.

R. J. Havel, Secretary; 20 North Wacker Dr., Room 720, Chicago 6, Ill.

Columbus and Central Ohio Committee on Corrosion

I. E. Davis, Chairman; Ohio Fuel Gas Co., 99 North Front St., Columbus, Ohio

W. C. Burns, Vice Chairman; Ohio Bell Telephone Co., 111 North Front St., Columbus, Ohio

J. H. Fitzgerald, Secretary; Columbia Gas System, 1600 Dublin Road, Columbus, Ohio

Directory of NACE Technical Committee Officers

Toledo and Northwestern Ohio Committee on Corrosion

O. V. Henrion, Chairman; Ohio Bell Telephone Co., 121 Huron St., Toledo 4, Ohio

J. D. Griffin, Vice Chairman; Ohio Fuel Gas Co., District Dept., 333 South Erie St., Toledo 4, Ohio.

I. H. Heitkamp, Secretary; Toledo Edson Co., 420 Madison Ave., Toledo 4, Ohio

Detroit Committee on Electrolysis

C. Chapin, Chairman; Dept. of Water Supply, 701 Water Board Bldg., Detroit 26, Mich.

P. Hough, Vice Chairman; Michigan Bell Telephone Co., 3800 Cadillac Tower, Detroit 26, Mich.

E. E. Westerhof, Secretary-Treasurer; Consumers Power Co., 212 W. Michigan Ave., Jackson, Mich.

Joint Electrolysis Committee of Various Utility Companies of Chicago

R. I. Perry, Chairman; Commonwealth Edison Co., 72 W. Adams St., Rm. 818, Chicago 90, Ill.

H. C. Boone, Secretary; Peoples Gas, Light & Coke Co., 122 S. Michigan Ave., Rm. 1732, Chicago 3, Ill.

T-7C Southeast Region Corrosion Coordinating Committee

E. W. Seay, Jr., Chairman; The Chesapeak & Potomac Tel. Co. of Va., 5550 Lynn Street, Norfolk 13, Va.

The Louisville (Ky.) Joint Electrolysis Committee

Stuart H. Gates, Chairman; Southern Bell Tel. & Tel. Co., Louisville, Ky.

John L. Gray, Vice Chairman; Louisville Gas & Electric Co., Louisville, Ky.

Walter Zell, Secretary; Louisville Gas & Electric Co., Louisville, Ky.

South Florida Corrosion Control Committee

J. B. Prime, Jr., Chairman; Florida Power & Light Co., P. O. Box 3100, Miami 30, Fla.

J. Frink, Vice Chairman; Houston Corp., Box 10400, St. Petersburg 33, Fla.

C. H. Montague, Secretary; Peoples Gas System, 564 N. E. 125th Street, North Miami 61, Fla.

Tidewater Corrosion Committee

E. W. Seay, Jr., Chairman; The Chesapeak & Potomac Tel. Co. of Va., 5550 Lynn Street, Norfolk 13, Va.

J. W. Berryman, Jr., Secretary; 3463 Fletcher Drive, Norfolk 13, Va.

T-7D South Central Region Corrosion Coordinating Committee

C. L. Mercer, Chairman; Southwestern Bell Tel. Co., Box 58, Westfield, Texas

C. L. Woody, Vice Chairman; United Gas Corporation, Box 2628, Houston, Texas

Houston Corrosion Coordinating Committee

C. L. Mercer, Chairman; Southwestern Bell Telephone Co., Box 58, Westfield, Texas

San Antonio Area Corrosion Committee

Carl M. Thorn, Vice Chairman; Southwestern Bell Tel. Co., P. O. Box 2540, San Antonio 6, Texas

I. A. Flodin, Secretary; School of Engineering, Robert College, Bebek, P. K. 8, Istanbul, Turney

Denver Metro Committee on Corrosion

H. L. Goodrich, Chairman; American Tel. & Tel. Co., 810 4th St., Denver 2, Colo.

F. F. Hassoldt, Vice Chairman; Denver Board of Water Commissioners, 144 West Colfax Ave., Denver, Colo.

H. A. Emery, Secretary; Public Service Co. of Colo., Gas Engineering Dept., Box 840, Denver 1, Colo.

T-7E Western Region Corrosion Coordinating Committee

I. C. Dietze, Chairman; Dept. of Water & Power, Box 3669 Terminal Annex, Los Angeles 54, Cal.

W. G. Collins, Vice Chairman; Pacific Tel. & Tel. Co., 760 Market St., Rm. 1136, San Francisco 2, Cal.

Central California Cathodic Protection Committee

J. A. Bessom, Chairman; Richfield Oil Corp., Box 147, Bakersfield, Cal.

C. E. Titus, Vice Chairman; Shell Oil Co., Box 329, Tracy, Cal.

T. J. Helms, Secretary; Superior Oil Co., Box 1031, Bakersfield, Cal.

San Diego County Underground Corrosion Committee

Ray Ditto, Chairman; California Water & Telephone Co., 386 Third Avenue, Chula Vista, Cal.

R. E. Hall, Vice Chairman; Union Oil Co., Research Center, Brea, Cal.

F. O. Waters, Secretary; 6326 Montezuma Road, San Diego 15, Cal.

Electrolysis Committee of Southern California

I. C. Dietze, Chairman; Dept. of Water & Power, City of Los Angeles, Box 3669, Terminal Annex, Los Angeles 54, Cal.

F. F. Knapp, Secretary; 308 Beaumont Drive, Vista, Cal.

The Joint Committee for the Protection of Underground Structures in the East Bay Cities

L. B. Hertzberg, Chairman; East Bay Municipal Utility District, 2127 Adeline St., Oakland, Cal.

W. G. Collins, Vice Chairman; Pacific Tel. & Tel. Co., 760 Market St., San Francisco 2, Cal.

C. K. Notley, Secretary-Treasurer; 1132 Walnut St., Berkeley 7, Cal.

The San Francisco Committee on Corrosion

A. J. Badura, Chairman; Western Union Tel. Co., 125 - 12th St., Oakland, Cal.

G. C. Hughes, Secretary; Pacific Tel. & Tel. Co., No. 1 McCoppin St., San Francisco, Cal.

T-7F Canadian Region Corrosion Coordinating Committee

C. L. Roach, Chairman; Bell Telephone of Canada, Room 1425, 1050 Beaver Hall Hill, Montreal, Quebec, Canada

Peter Dunkin, Vice Chairman; Union Gas Co. of Canada, Ltd., 48 Fifth St., Chatham, Ontario, Canada

Southern Ontario Committee on Electrolysis

G. I. Russell, Chairman; Interprovincial Corrosion Control Co., Ltd., Box 310, Burlington, Ontario, Canada

L. F. Heverly, Vice Chairman; Trans-Canada Pipe Lines Ltd., 150 Eglinton Ave. E., Toronto 12, Ontario, Canada

D. W. Lemon, Secretary; Sarnia Products Pipe Line, Imperial Oil Ltd., Box 380, Waterdown, Ontario, Canada

T8 Refining Industry Corrosion

Cecil Phillips, Jr., Chairman; Humble Oil & Refining Co., Humble Division, 1506 East Texas Ave., Baytown, Texas

R. D. Merrick, Vice Chairman; Esso Research & Engineering Co., Box 209, Madison, N. J.

F. B. Hamel, Secretary; Standard Oil Co. of Ohio, Midland Bldg., Cleveland, Ohio

T-8A Chemical Cleaning

K. R. Walston, Chairman; Standard Oil Co. (Ind.), 2400 New York Ave., Whiting, Ind.

C. M. Loucks, Vice Chairman; Materials & Methods, Inc., 23800 Center Ridge Road, Westlake, Ohio

R. L. Hildebrand, Secretary; Sinclair Refining Co., 400 East Sibley Blvd., Harvey, Ill.

T-8B Refinery Industry Corrosion, Los Angeles Area

W. G. Welter, Chairman; 10148 Larrylyn Dr., Whittier, Cal.

E. B. Marquand, Vice Chairman; Aluminum Co. of America, 1145 Wilshire Blvd., Los Angeles 17, Cal.

C. M. Cooper, Secretary; Standard Oil Co. of Cal., El Segundo Refinery, El Segundo, Cal.

T9 Marine Biological Deterioration

A. P. Richards, Chairman; Clapp Laboratories, Washington St., Duxbury, Massachusetts

T-9A Biological

Charles E. Lane, Chairman; Marine Laboratory, University of Miami, Coral Gables 34, Fla.

T-9B Preservatives and Their Appraisal

Harry Hochman, Chairman; 23652 Collins St., Woodland Hills, Cal.

V. B. Volkening, Vice Chairman; Route 1, Freeport, Texas

TECHNICAL PAPERS SCHEDULED FOR AUGUST PUBLICATION

Ablation Behavior of Materials Subjected to Missile Re-Entry Heat Flux Rates, by R. M. Krupka and D. E. Taylor

Effect of pH (6.6-14.0+) Upon Aerobic Corrosion Fatigue of Steel, by F. J. Radd, L. H. Crowder and L. H. Wolfe

Material Problems Associated With Uncooled Rocket Nozzles, by Jesse D. Walton and C. R. Mason, Jr.

High Temperature Lubrication in Reactive Atmospheres, by Robert L. Johnson, Max A. Swikert and Donald H. Buckley

Development of Thin Metal Film Corrosion Indicators, by David Roller and G. H. Rohrback

Cathodic Protection for Metallic Water Tanks, by C. A. Bauer and L. C. Eddy

Coating Performance by Statistical Methods, by Frank E. Cook and Arthur S. Marthens

Leaching Action of Various Materials by High Purity Water, by J. B. Goodson and E. L. Knoedler

Performance of Zinc Anodes for Cathodic Protection in Sea Water, by L. J. Waldron and M. H. Peterson

Oxidation and Corrosion of Zirconium and its Alloys, by B. Cox

Also Available

STRESS CORROSION CRACKING

Fifteen articles from CORROSION on various aspects of high temperature, and ambient temperature sulfide stress corrosion cracking.

NACE MEMBERS **$3.50**

OTHERS **$5.00**

Remittances must accompany all orders for literature the aggregate cost of which is less than $5. Orders of value greater than $5 will be invoiced if requested. Send orders to National Association of Corrosion Engineers, 1061 M & M Bldg., Houston, Texas. Add 65c per package to the prices given above for Book Post Registry to all addresses outside the United States, Canada and Mexico.

ASTM-NACE Report

★

STRESS-CORROSION CRACKING OF AUSTENITIC CHROMIUM-NICKEL STAINLESS STEELS

★

ASTM Special Technical Publication No. 264

★

A report sponsored jointly by the American Society for Testing Materials Committee A-10 on Iron-Chromium, Iron-Nickel and Related Alloys and NACE Unit Committee T-5E on Stress-Corrosion Cracking of Austenitic Stainless Steels. The 92-page, 8¼ x 11 inch booklet is divided into two parts. Part I consists of a review and discussion of 129 case histories from 25 sources experiencing stress-corrosion cracking of austenitic stainless steels. Part II covers information on current research activity and a review of present knowledge of the basic mechanism.

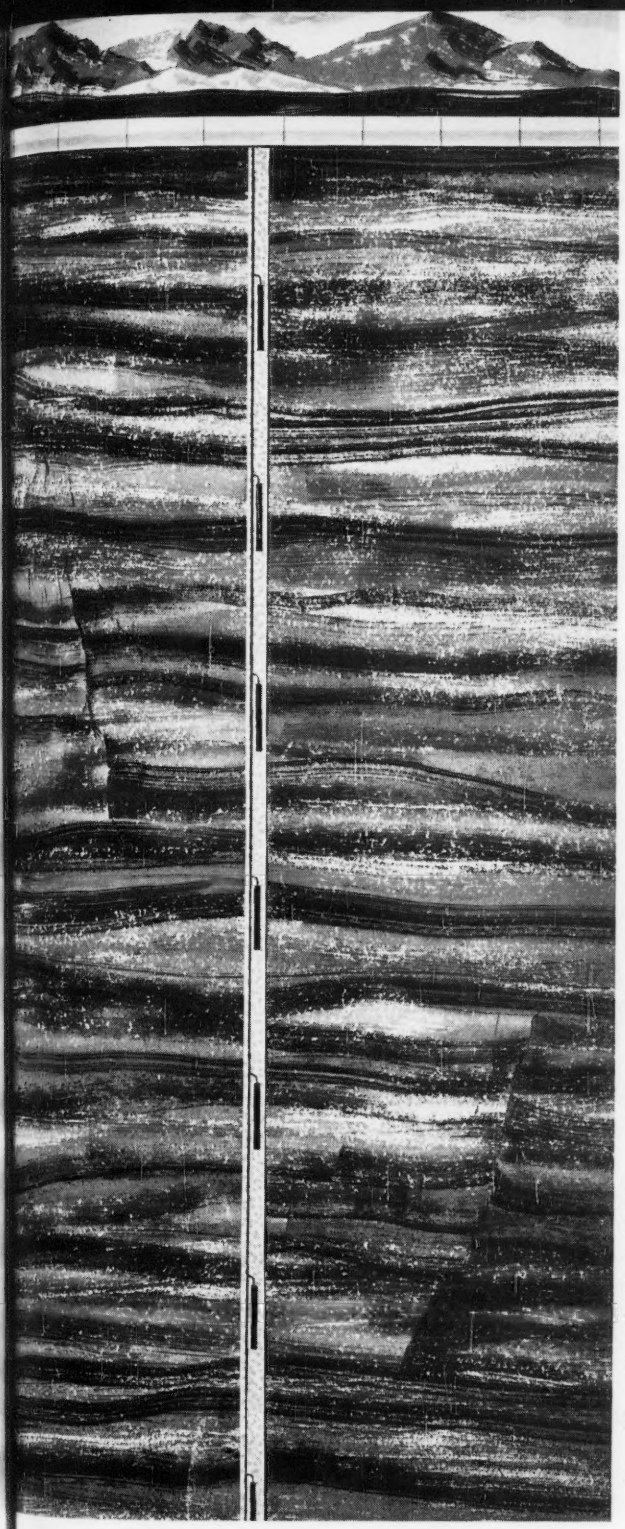
There is a comprehensive bibliography and abstracts covering years 1935-59.

NACE, ASTM Members, per copy $4.80

Non-Members, per copy $6.00

NATIONAL ASSOCIATION of CORROSION ENGINEERS

1061 M & M Bldg. Houston 2, Texas



for "deep well"
installation, specify

Duriron®

impressed current Anodes

Durco high silicon iron alloys (Duriron, Durichlor, and D-51) are being used almost exclusively for new deep well anode installations.

Durco anodes combine the advantages of:

1 PERMANENCY *(Weight loss 1/20 of that of steel)*

2 EASE OF INSTALLATION *(Bulk volume of scrap steel is avoided)*

3 MINIMUM TOTAL COST *(No backfill or pre-packing of anodes required)*

Durco high silicon iron alloys are resistant to sea, brackish, and fresh waters, as well as all soil environments. Complete details are contained in Bulletin DA/6.

THE DURIRON COMPANY, INC.
DAYTON, OHIO

DURCO
CORROSION RESISTING ALLOYS & EQUIPMENT

CORBAN

17 varieties available to combat all well corrosion problems

Corban® is a family of polar-type corrosion inhibitors. It has been found extremely effective for preventing and combating corrosion problems in oil and gas wells.

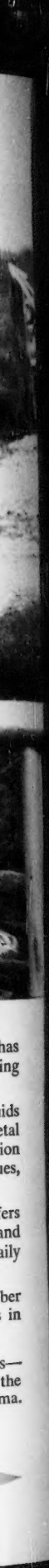
When introduced into a well, Corban mixes with the fluids encountered and is carried throughout the well, coating all metal surfaces. The film of Corban offers protection against corrosion until removed through erosion. While the treatment continues, the film is continually renewed.

The new inhibitor "squeeze" technique, using Corban, offers extended corrosion protection to sour crude, sweet crude and gas condensate wells. This technique eliminates the need for daily or weekly well supervision.

Corban is available in both liquid and stick form in a number of formulas. Each formula is designed to give the best results in a specific application.

And, Corban is available from more than 150 Dowell stations—throughout the oil country. For information or service, contact the Dowell station nearest you. Or write Dowell, Tulsa 1, Oklahoma.

Products for the oil industry

DIVISION OF THE DOW CHEMICAL COMPANY

DOWELL